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(71) Applicant: **SINCO RICERCHE S.p.A.**
28048 Verbania Pallanza (Verbania) (IT)

(72) Inventors:
• **Al Ghatta, Hussain**
03014 Fiuggi (Frosinone) (IT)

• **Vosa, Renato**
81022 Casagiove (Caserta) (IT)
• **Severini, Tonino**
00034 Colleferro (Roma) (IT)
• **Cobror, Sandro**
86077 Pozzilli (Isernia) (IT)

(74) Representative:
Gerbino, Angelo et al
c/o **JACOBACCI & PERANI S.p.A.**
Corso Regio Parco, 27
10152 Torino (IT)

(54) **Flexible polyester foams**

(57) A foamed cellular material which can be obtained from foamed aromatic polyester resins with a bulk density of 50 to 700 kg/m³ by heating in vacuum to temperatures which are higher than the T_g of the material and lower than its melting point. The foamed material, generally in the form of a sheet or panel, has high-level characteristics in terms of flexibility and dimensional thermostability depending on the degree of crystallinity after the vacuum treatment.

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Description

[0001] The present invention relates to foamed cellular materials (foams) derived from polyester resin, comprising materials having high flexibility and satisfactory elastic recovery as well as thermostable and flexible materials, and to their preparation method.

[0002] Conventional foamed polyester materials have valuable mechanical properties but poor flexibility.

[0003] The rigidity of the material excludes them from applications where flexibility is an essential requirement.

[0004] US-A- 5 110 844 describes foamed polyester materials which have the characteristics of synthetic leather and are obtained by subjecting a partially foamed polyester sheet to further foaming and then compressing it at a temperature below the Tg of the material.

[0005] EP-A-0 442 759 describes thermostable but rigid foamed polyester materials obtained from a partially foamed polyester material which is cooled at the outlet of the extruder to a temperature below the Tg of the material, so as to maintain crystallinity at relatively low values, lower than 15%, subsequently subjecting it to further foaming in an aqueous environment at temperatures above the Tg of the material and then heating it to temperatures above 100°C in a non-aqueous environment.

[0006] The treatment with water causes the absorption of water, which then expands at a temperature above 100°C, thus producing the further foaming of the material.

[0007] US-A- 4 284 596 describes a process for preparing polyester foams starting from polyester resins with the addition of a polyepoxy, in which the resin, at the outlet of the extruder and while it is still in the molten state, is made to pass through a chamber at reduced pressure and is then solidified.

[0008] The reduced pressure (200-300 millibar) applied to the still-molten resin allows to obtain low-density foamed materials with cells having uniform shape and volume which are uniformly distributed within the mass of the foamed material. The resulting foam is not flexible.

[0009] A method has now been unexpectedly found which allows to obtain a wide range of foamed cellular materials from aromatic polyester resins having high flexibility and elastic recovery characteristics or which combine dimensional thermostability and flexibility.

[0010] The method according to the invention comprises the following steps:

- a) extrusion-foaming of a foamable aromatic polyester resin to obtain a foamed material with a bulk density between 50 and 700 kg/m³;
- b) cooling of the foamed material at the outlet of the extruder to temperatures and with cooling rates which do not allow the material to reach a degree of crystallinity higher than 15%;
- c) heating of the material to a temperature above its Tg but below its melting point, if it is not already at such a temperature, with heating rates such as to prevent the material from reaching crystallinity values above 15%;
- d) vacuum treatment of the foamed material heated as in c), keeping it at a temperature which is higher than its Tg but lower than the melting point of the material for a time sufficient to determine a decrease in the bulk density of the material of at least 30% with respect to the density after step a);
- e) return of the material to atmospheric pressure, preferably after cooling it to ambient temperature whilst it is still under vacuum.

[0011] The material after step e) generally has a bulk density of less than 500 kg/m³, preferably less than 100 kg/m³.

[0012] The cooling of the material at the outlet of the extruder is preferably performed with water at cooling rates which maintain the crystallinity of the material between 5 and 12%.

[0013] It is also possible to cool the extruded material, for example, in the form of a panel with a thickness of 10 mm or more, bringing it to a temperature such that in the core of the panel the temperature corresponds to the one at which the material is to be subjected to the vacuum treatment (for example 180°C), and to directly introduce the thus cooled material into the vacuum chamber.

[0014] The temperature above Tg to which the material is brought for the vacuum treatment is comprised for example between 80° and 180°C. By working at temperatures between approximately 80° and 130°C it is possible to obtain even considerable decreases in density without significantly increasing the crystallinity of the material. Highly flexible materials, having good elastic recovery, are thus obtained.

[0015] By working at higher temperatures, for example 170 - 180°C, a considerable decrease in bulk density is still achieved together with a significant increase in crystallinity, which can reach 30-40% or more; at these values one obtains a material which is still flexible and has high dimensional thermostability characteristics.

[0016] The heating of the material to bring it to the temperature of the vacuum treatment can be performed in an air oven or with pressurized water vapor or with other means.

[0017] The duration of the vacuum treatment is such as to decrease the bulk density by at least 30% with reference to the density of the material after step b).

[0018] The times are generally between 2 and 20 minutes, preferably 15 to 20 minutes. For example, a time of 15 minutes produces decreases in bulk density of 70-80% or more starting from sheets 2-4 mm thick, either operating at temperatures of 90-130°C or at higher temperatures (170 - 180°C).

[0019] In the case of treatment at high temperatures (170 - 180°C), if the treatment is continued for more than 15-20 minutes, for example 60 minutes, the material collapses and bulk density increases considerably.

[0020] By working at lower temperatures (80°C) and increasing the duration of the treatment (60 minutes) the bulk density remains practically constant.

[0021] The vacuum to which the material is subjected is, by way of indication, 20-40 mbar; harder vacuums and less extreme vacuums can also be used.

[0022] The harder the vacuum, the greater the effect on the decrease in density, other conditions being equal.

[0023] Preferably, the material is cooled to ambient temperature while it is still under vacuum; this produces a greater decrease in density than with material cooled at atmospheric pressure.

[0024] The preparation of the foamed cellular material by means of extrusion-foaming processes of foamable polyester resins is performed according to conventional methods, for example by extruding the polyester resin in the presence of a polyfunctional compound, such as for example a dianhydride of a tetracarboxylic acid.

[0025] Pyromellitic dianhydride (PMDA) is a representative and preferred compound.

[0026] Methods of this type are described in US-A- 5 000 991 and US-A- 5 288 764, the description of which is included by reference.

[0027] As an alternative, and as a preferred method, the polyester resin is upgraded in the solid state in the presence of a dianhydride of a tetracarboxylic aromatic acid (PMDA is the preferred compound) under conditions allowing to obtain a resin with an intrinsic viscosity of more than 0.8 dl/g, melt viscosity higher than 2500 PA · s and melt strength of more than 8 cN.

[0028] The blowing agents that can be used are of a known type: they can be easily volatile liquid hydrocarbons, such as for example n-pentane, or inert gases, such as nitrogen and carbon dioxide, or chemical blowing compounds.

[0029] The blowing agents are generally used in amounts between 1 and 10% by weight on the resin.

[0030] The foamed material is generally extruded in the form of a sheet with a thickness of a few millimeters, by way of example 2-4 mm, or as a panel with a thickness of about 20-50 mm.

[0031] For "foamable polyester resin" it is herein intended a resin which has the above described rheological characteristics which make it foamable or a resin which is capable of developing these characteristics during extrusion.

[0032] The aromatic polyester resins to which the process of the invention is applied are obtained by polycondensation of a diol with 2-10 carbon atoms with a dicarboxylic aromatic acid, such as for example terephthalic acid or lower alkyl diesters thereof.

[0033] Polyethylene terephthalate and alkylene terephthalates copolymers in which up to 20% in moles of terephthalic acid units is replaced with units of isophthalic acid and/or naphthalene dicarboxylic acids are preferred resins.

[0034] The polyester resins, preferably polyethylene terephthalate and copolyethylene terephthalates, can be used in mixtures with other polymers such as polyamides, polycarbonates, polycarbonate and polyethylene glycol used in amounts preferably up to about 40% by weight on the blend. The polymer is extruded with the polyester resin in the presence of pyromellitic dianhydride or a similar anhydride in an amount between 0.1 and 2% by weight on the blend and the resulting alloy is then upgraded in the solid state at temperatures between 160°C and 220°C.

[0035] An example of embodiment of the method is as follows.

[0036] The foamed material, once it has left an annular extrusion head, is fitted on a water-cooled sizing mandrel and then cut.

[0037] The resulting sheet is then pulled and rolled so as to form rolls from which the sheet is drawn continuously into a heating oven, in order to bring the temperature of the material to the chosen value, and is then introduced in a vacuum chamber from which it passes into a water bath whilst it is still under vacuum and is then returned to atmospheric pressure.

[0038] The characteristics of flexibility and dimensional thermostability of the material obtained with the method according to the invention depend on the degree of crystallinity and on the bulk density of the material.

[0039] The material offers flexibility and good elastic recovery when its crystallinity is below 15-20% and is more rigid, but provided with good dimensional thermostability, when the degree of crystallinity is around 30-35%.

[0040] The foamed cellular material that can be obtained with the method according to the present invention from foamed material with a bulk density of 50 to 700 kg/m³ by heating under vacuum to temperatures above the T_g of the material and below its melting point and by subsequent cooling has the following characteristics when subjected to constant-stress compression cycles (creep).

[0041] The characteristics, referred to a sheet of polyethylene terephthalate or copolyethylene terephthalates with 1-20% isophthalic acid units, with a crystallinity of less than 15% and a density of less than 100 kg/m³, are:

- maximum creep deformation: between 10 and 60%;

- residual deformation after creep (after 120 minutes): 10 to 30%;
- elastic recovery: between 40 and 80%.

[0042] The characteristics of a sheet with a density between 200 and 300 kg/m³ and with a crystallinity of less than 15% are:

- maximum creep deformation: between 5 and 15%;
- residual deformation after creep (after 120 minutes): 1 to 5%;
- elastic recovery: between 75 and 90%.

[0043] The characteristics of the material with a crystallinity of more than 30%, particularly between 35 and 40%, are as follows, with reference to a sheet with a density of less than 100 kg/m³:

- maximum dimensional stability temperature (stressed at <5% at 30 MPa): up to 150°C;
- maximum residual creep deformation: 6-20%;
- residual deformation after creep for 120 minutes: 2-10%;
- elastic recovery: 50-80%.

[0044] In the case of a polyethylene terephthalate material with 10% isophthalic acid, the maximum dimensional stability temperature is 148°C.

[0045] In the case of a material with a density of 200 to 300 kg/m³, the maximum dimensional stability temperature can reach 165°C, whilst the other properties remain similar to the material having a density of less than 200 kg/m³.

[0046] The measurements under constant stress were performed with the following method.

[0047] The tested samples were circular (disks with a diameter of approximately 20 mm).

[0048] A Perkin-Elmer dynamic-mechanical analyzer DMA 7 operating in helium (40 cc/min) was used in a configuration with parallel sample plates having a diameter of 10 mm.

[0049] The samples were then subjected to a series of constant-force stresses (creep) with a load of 2600 mN, as explained hereafter.

[0050] The sample was placed between the two plates and compressed with a practically nil load (1 mN).

[0051] The test began after approximately 5 min stabilization and consisted in applying a load of 2600 mN for 5 min (creep).

[0052] After this period, the load was removed instantaneously, allowing the sample to recover for 5 min.

[0053] This procedure was repeated 12 times for 120 minutes on the same sample, so as to produce a creep-recovery sequence.

[0054] The trace of the deformations undergone by the sample as a consequence of the individual creep-recovery steps was thus recorded.

[0055] During creep the sample underwent an elastic-plastic deformation which was (partially) recovered during the recovery step. The recovered part was considered to be an elastic deformation, whilst the unrecovered part remained as a permanent deformation (footprint).

[0056] It was found that after about 120 min of creep-recovery sequence the situation stabilized, producing constant values for elastic and permanent deformation.

[0057] The degree of crystallinity of the material was determined by DSC from the melting enthalpy of the material minus the crystallization enthalpy of the material and was compared with the enthalpy of the perfectly crystalline material (117 kJ/mole in the case of PET); in the case of crystallized material, crystallization enthalpy is equal to 0 J/g.

[0058] Rheological measurements were conducted at temperatures between 260 and 300°C according to the type of polyester resin and to the rheological characteristics thereof, using a Geotterd capillary rheometer (reference should be made to US-A- 5 362 763 for a more detailed description of the method).

[0059] For example, when the polyester resin was a polyethylene terephthalate homopolymer, melt strength measurements were performed at 280°C; they were instead performed at 260°C when the resin was a copolyethylene terephthalate containing 10% isophthalic acid units.

[0060] Melt viscosity was determined at 300°C for PET and at 280°C for the copolyester.

[0061] Intrinsic viscosity was determined by means of solutions of 0.5 g of resin in 100 ml of a 60/40 mixture by weight of phenol and tetrachloroethane at 25°C, working according to ASTM 4063-86.

[0062] Bulk density was determined by the ratio between the weight and the volume of the foamed material.

[0063] The following examples are given to illustrate but not to limitate the invention.

EXAMPLE 1 (PRODUCTION OF FOAMED PET SHEET)

[0064] 90 kg/h of polyethylene terephthalate homopolymer material having a melt strength of 100-150 cN, melt viscosity of 1800 Pa · s at 300°C and 10 rad/sec and intrinsic viscosity of 1.25 dl/g, obtained by upgrading the polymer at 210°C in the presence of 0.4% by weight of pyromellitic dianhydride (COBITECH™), were fed continuously to a two-screw extruder with a screw diameter of 90 mm.

[0065] A static mixer was placed after the screws to improve homogenization of the various components of the blend.

[0066] The temperatures set on the extruder were 280°C in the melting region, 280°C in the compression region, 270°C in the mixing region and 265°C at the extrusion head.

[0067] The screws of the extruder rotated at 18 rpm.

[0068] 1.8% by weight of n-pentane (blowing agent) was added to the PET in the region of the extruder located after the melting of the polymer and thoroughly mixed with the polymeric matrix.

[0069] The PET/n-pentane composition, once mixed, was extruded through an annular head having a diameter of 90 mm and an extrusion opening of 0.23 mm. A sizing mandrel with a diameter of 350 mm and a length of 750 mm, cooled with water at 20°C, was arranged on the extrusion head.

[0070] The foamed material, once it had left the extrusion head, was fitted on the mandrel and cut. The resulting sheet was pulled and rolled to produce rolls.

[0071] The resulting sheet had the following characteristics:

- density	0.145 g/cm ³
- weight	290 g/m ²
- thickness	2 mm
- average cell diameter	300 µm
- degree of crystallization	8%

EXAMPLE 2 (PRODUCTION OF FLEXIBLE FOAMED PET SHEET)

[0072] The sheet produced as described in example 1 was subjected to a treatment as described hereafter.

[0073] The sheet was drawn continuously in a heating oven which brought the sheet to a temperature of approximately 115°C in approximately 5 minutes after which the sheet was introduced in a vacuum sizing device, where the residual pressure was approximately 30 mbar.

[0074] The retention time of the sheet inside the vacuum chamber was approximately 5 minutes: the thus treated sheet was then passed through a water bath kept at 25°C and then returned to atmospheric pressure.

[0075] The characteristics of the resulting sheet were as follows:

- density	0.029 g/cm ³
- weight	290 g/m ²
- thickness	10 mm
- degree of crystallization	10%

[0076] The sheet produced according to this treatment is termed "flexible sheet" and was subjected to compression measurement cycles in order to evaluate its compression resistance and its elastic recovery. All tests were performed in parallel with the sheet produced during the first step, which is termed "base sheet".

[0077] Table 1 lists the values found during these characterizations.

TABLE 1

	BASE SHEET	FLEXIBLE SHEET
Maximum creep deformation (%)	6.4	39.6
Residual deformation after creep (after 120 minutes)(%)	4.1	22.4
permanent deformation (%)	64.1	56.6
elastic recovery (%)	35.9	43.4

[0078] These measurements were performed by means of a thermomechanical analyzer by subjecting the samples to 12 consecutive compression and decompression cycles.

EXAMPLE 3 (PRODUCTION OF THERMOSTABLE FLEXIBLE FOAMED PET SHEET)

[0079] The sheet produced in example 1 was subjected to a treatment as described hereafter.

[0080] The sheet was pulled continuously in a heating oven, which brought the sheet to a temperature of approximately 125°C in approximately 5 minutes; after this, the sheet was introduced in a sizing device under vacuum, in which the residual pressure was approximately 30 mbar. The retention time of the sheet inside the vacuum chamber was approximately 8 minutes; the sheet was kept at a temperature of 180°C.

[0081] Before leaving the chamber under vacuum, the thus treated sheet was passed through a bath of water kept at 25°C and then returned to atmospheric pressure.

[0082] The characteristics of the resulting sheet are as follows:

- density 0.033 g/cm³
 - weight 290 g/m²
 - thickness 8.8 mm
 - degree of crystallization 35%

[0083] The sheet produced according to this treatment, termed "thermostable flexible sheet", was subjected to compression measurement cycles to evaluate both compression resistance and elastic recovery as well as temperature-dependent deformation.

[0084] All tests were conducted in parallel with the sheet produced during the first step, which is termed "base sheet".

[0085] Table 2 lists the values found during these characterizations.

TABLE 2

	BASE SHEET	THERMOSTABLE FLEXIBLE SHEET
Maximum dimensional stability temperature (stress < 5%) at 30000 Pa	<90°C	<150°C
Maximum creep deformation (%)	6.4	11.6
Residual deformation after creep (after 120 min)(%)	4.1	3.9
permanent deformation (%)	64.1	33.6
elastic recovery (%)	35.9	66.4

[0086] These measurements were performed by means of a thermomechanical analyzer.

EXAMPLE 4 (PRODUCTION OF A THERMOSTABLE FLEXIBLE FOAMED PET SHEET: WATER AT 125°C)

[0087] The sheet produced as described in example 1 was subjected to a treatment as described hereafter.

[0088] The sheet was pulled continuously and heated by means of water at 125° for 5 minutes, after which the sheet was introduced in a sizing device under vacuum, in which the residual pressure was approximately 30 mbar.

[0089] The retention time of the sheet inside the chamber under vacuum was approximately 8 minutes. The sheet was kept at a temperature of 180°C before leaving the chamber under vacuum and then passed through a bath of water kept at 25° and then returned to atmospheric pressure.

[0090] The characteristics of the resulting sheet were:

- density 0.038 g/cm³
 - weight 290 g/m²
 - thickness 7.6 mm
 - degree of crystallization 38%

[0091] The sheet produced according to this treatment, termed "thermostable flexible sheet", was subjected to compression measurement cycles in order to evaluate both compression resistance and elastic recovery as well as temperature-dependent deformation. All tests were conducted in parallel with the sheet produced during the first step, which is termed "base sheet".

[0092] Table 3 lists the values observed during these characterizations.

TABLE 3

	BASE SHEET	THERMOSTABLE FLEXIBLE SHEET
Maximum dimensional stability temperature (stress < 5%) at 30000 Pa	<90°C	<160°C
Maximum creep deformation (%)	6.4	10
Residual deformation after creep (after 120 min)(%)	4.1	3.7
permanent deformation (%)	64.1	37
elastic recovery (%)	35.9	63

[0093] These measurements were conducted with a thermomechanical analyzer.

EXAMPLE 5 (PRODUCTION OF A FOAMED PET PANEL)

[0094] 90 kg/h of copolyethylene terephthalate material containing 10% by weight of isophthalic acid with a melt strength of 100-150 cN, intrinsic viscosity of 1.25 dl/g and melt viscosity of 1800 Pa · s at 280°C (obtained by upgrading the polymer at 280°C in the presence of 0.4% by weight of pyromellitic dianhydride (COBITECH™) were fed continuously in a twin-screw extruder with a screw diameter of 90 mm.

[0095] A static mixer was arranged downstream of the screws in order to improve the homogenization of the various components of the blend.

[0096] The temperatures set on the extruder were 260°C in the melting region, 250°C in the compression region, 240°C in the mixing region and 225°C in the extrusion region.

[0097] The screws of the extruder rotated at 18 rpm.

[0098] 2.4% by weight of blowing agent 134a (1,1,1,2 tetrafluoroethane) was added to the PET in the region of the extruder located after the melting of the polymer and thoroughly mixed with the polymeric matrix.

[0099] The PET/134a composition, once mixed, was extruded through a flat head.

[0100] The resulting panel had the following characteristics:

- density 0.115 g/cm³
- thickness 22 mm
- average cell diameter 280 µm
- degree of crystallization 8%

EXAMPLE 6 (PRODUCTION OF A FLEXIBLE FOAMED PET PANEL)

[0101] The panel produced as described in example 5 was subjected to a treatment performed a few seconds after extrusion as described hereafter.

[0102] The extruded panel was cooled in the sizing region, and once a temperature of 180°C had been reached in the core of the panel, said panel was inserted in a sizing device under vacuum, where the residual pressure was approximately 30 mbar. The residence time of the panel inside the chamber under vacuum was approximately 5 minutes. The panel was kept at a temperature of approximately 120°C before leaving the chamber under vacuum and then was made to pass through a bath of water kept at 25°C and then returned to atmospheric pressure.

[0103] The characteristics of the resulting panel were:

- density 0.030 g/cm³
- thickness 55 mm
- degree of crystallization 10%

[0104] The resulting panel (termed "flexible panel") was subjected to compression measurement cycles in order to evaluate compression resistance and elastic recovery. All tests were conducted in parallel on the panel produced during the first step (base panel).

[0105] Table 4 lists the measured values:

TABLE 4

	BASE PANEL	FLEXIBLE PANEL
Maximum creep deformation (%)	2.4	24
Residual deformation after creep (after 120 min)(%)	1.6	5.7
permanent deformation (%)	66	23.7
elastic recovery (%)	34	76.3

EXAMPLE 7 (PRODUCTION OF A THERMOSTABLE FLEXIBLE FOAMED PET PANEL)

[0106] The panel produced as described in example 5 was subjected to a treatment performed a few seconds after extrusion, as described hereafter.

[0107] The extruded panel was cooled in the sizing region and once it had reached a temperature of 180°C in the core of the panel it was introduced in a sizing device under vacuum, where the residual pressure was approximately 30 mbar. The residence time of the panel inside the chamber under vacuum was approximately 10 minutes. The panel was kept at a temperature of 180°C and before leaving the chamber under vacuum the panel was passed through a bath of water kept at 25°C and then returned to atmospheric pressure.

[0108] The characteristics of the resulting panel were as follows:

- density 0.038 g/cm³
 - thickness 52 mm
 - degree of crystallization 36%

[0109] The panel produced according to this treatment (termed "thermostable flexible panel") was subjected to compression measurement cycles to evaluate both compression resistance and elastic recovery as well as temperature-dependent deformation. All tests were conducted in parallel on the panel produced during the first step (base panel).

[0110] Table 5 lists the measured values.

TABLE 5

	BASE PANEL	THERMOSTABLE FLEXIBLE PANEL
Maximum dimensional stability temperature (stress < 5%) at 30000 Pa	<80°C	<148°C
Maximum creep deformation (%)	2.4	16
Residual deformation after creep (after 120 min)(%)	1.6	5.1
permanent deformation (%)	66	31.9
elastic recovery (%)	34	68.1

EXAMPLE 8 (PRODUCTION OF FOAMED PET SHEET)

[0111] 90 kg/h of polyethylene terephthalate homopolymer (COBITECH™) used in example 1 were fed continuously to a twin-screw extruder with a screw diameter of 90 mm.

[0112] A static mixer was placed downstream of the screws in order to improve the homogenization of the various components of the blend.

[0113] The temperatures set on the extruder were 280°C in the melting region, 280°C in the compression region, 270°C in the mixing region and 265°C on the extrusion head.

[0114] The screws of the extruder rotated at 15 rpm.

[0115] 2.5% by weight of nitrogen (blowing agent) was added to the PET in the region of the extruder located after the melting of the polymer and was thoroughly mixed in with the polymeric matrix.

[0116] The PET/N₂ composition, once mixed, was extruded through an annular head having a diameter of 120 mm and an extrusion opening of 0.14 mm.

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[0117] A sizing mandrel with a diameter of 350 mm and a length of 750 mm, cooled with water at 20°C, was placed on the extrusion head.

[0118] The foamed material, after leaving the extrusion head, was fitted on the mandrel and cut. The resulting sheet was pulled and rolled to produce rolls.

5 [0119] The resulting sheet had the following characteristics:

- density 0.400 g/cm³
- weight 500 g/m²
- thickness 1.25 mm
- 10 - average cell diameter 130 µm
- degree of crystallization 10%

EXAMPLE 9 (PRODUCTION OF A SHEET OF FLEXIBLE FOAMED PET)

15 [0120] The sheet produced as described in example 8 was subjected to a treatment as described hereinafter.

[0121] The sheet was pulled continuously in a heating oven which brought the sheet to a temperature of approximately 115°C in approximately 3 minutes, after which the sheet was placed in a sizing device under vacuum, in which residual pressure was approximately 30 mbar. The residence time of the sheet was approximately 5 minutes and the temperature was kept at 115°C. Before leaving the chamber under vacuum, the sheet thus treated was passed through
20 a water bath kept at 25°C and then returned to atmospheric pressure.

[0122] The characteristics of the resulting sheet were as follows:

- density 0.260 g/cm³
- weight 500 g/m²
- 25 - thickness 1.95 mm
- degree of crystallization 11%

[0123] The sheet produced according to this treatment (termed "N₂ flexible sheet") was subjected to compression measurement cycles in order to evaluate both compression resistance and elastic recovery. All tests were conducted in
30 parallel on the sheet produced during the first step (N₂ base sheet).

[0124] Table 6 lists the values found during these characterizations.

TABLE 6

35		N ₂ BASE SHEET	N ₂ FLEXIBLE SHEET
	Maximum creep deformation (%)	2.9	8.5
	Residual deformation after creep (after 120 min) (%)	0.8	1.2
40	permanent deformation (%)	27.6	14.1
	elastic recovery (%)	72.4	85.9

45 [0125] These measurements were performed by means of a thermomechanical analyzer, subjecting the samples to 12 consecutive compression and decompression cycles.

EXAMPLE 10 (PRODUCTION OF A SHEET OF THERMOSTABLE FLEXIBLE FOAMED PET)

[0126] The sheet produced in example 8 was subjected to a treatment as described hereafter.

50 [0127] The sheet was pulled continuously in a heating oven which brought the sheet to a temperature of 115°C in approximately 3 minutes, after which the sheet was introduced in a sizing device under vacuum, where the residual pressure was approximately 30 mbar. The residence time of the sheet inside the chamber under vacuum was approximately 5 minutes; the sheet was kept at a temperature of 180°C.

[0128] Before leaving the chamber under vacuum, the sheet was passed through a water bath kept at 25°C and then
55 returned to atmospheric pressure.

[0129] The characteristics of the resulting sheet were:

- density 0.243 g/cm³

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- weight 500 g/m²
- thickness 2.05 mm
- degree of crystallization 37%

5 [0130] The sheet produced according to this treatment (termed "N₂ thermostable flexible sheet") was subjected to compression measurement cycles in order to evaluate resistance to compression and elastic recovery as well as temperature-dependent deformation. All tests were conducted in parallel on the sheet produced during the first step (base sheet).

[0131] Table 7 lists the values found during these characterizations.

10

TABLE 7

	N ₂ BASE SHEET	N ₂ THERMOSTABLE FLEXIBLE SHEET
15 Maximum dimensional stability temperature (stress < 5%) at 30000 Pa	<90°C	<165°C
Maximum creep deformation (%)	2.9	7.4
20 Residual deformation after creep (after 120 min)(%)	0.8	1.7
permanent deformation (%)	27.8	24
elastic recovery (%)	72.4	76

25 [0132] These measurements were taken with a thermomechanical analyzer.

COMPARISON EXAMPLE 1

30 [0133] A sheet produced as described in example 1 of US-A- 5 110 844 was subjected to thermomechanical characterization and compared with the sheet of example 4.

[0134] The results of these characterizations are listed in Table 8.

TABLE 8

	BASE SHEET	THERMOSTABLE FLEXIBLE SHEET	SHEET ACCORDING TO EXAMPLE 1 OF US-A-5 110 884
35 Maximum dimensional stability temperature (stress < 5%) at 30000 Pa	<90°C	<160°C	<90°C
Maximum creep deformation (%)	6.4	10	6.1
40 Residual deformation after creep (after 120 min) (%)	4.1	3.7	4
45 permanent deformation (%)	64.1	37	65.6
elastic recovery (%)	35.9	63	34.4

50 [0135] The measurements were taken with a thermomechanical analyzer.

COMPARISON EXAMPLE 2

[0136] A sheet produced as described in Example 1 of US-A- 4 284 596 was subjected to thermomechanical characterization and compared with the sheet of example 4.

55 [0137] The results of these characterizations are listed in Table 9.

TABLE 9

	BASE SHEET	THERMOSTABLE FLEXIBLE SHEET	SHEET ACCORDING TO EXAMPLE 1 OF US- A- 4 284 596
Maximum dimensional stability tempera- ture (stress < 5%) at 30000 Pa	<90°C	<160°C	<90°C
Maximum creep deformation (%)	6.4	10	2.2
Residual deformation after creep (after 120 min) (%)	4.1	3.7	2
permanent deformation (%)	64.1	37	91
elastic recovery (%)	35.9	63	9

[0138] The measurements were taken with a thermomechanical analyzer.

20 Claims

1. A foamed cellular material derived from aromatic polyester resins, obtainable from aromatic polyester foamed cellular material having a bulk density of 50 to 700 kg/m³ by heating under vacuum at temperatures higher than the T_g of the material and lower than the melting point thereof, for a time sufficient to achieve a decrease in bulk density of at least 30%.
2. A foamed cellular material according to claim 1, having a degree of crystallinity of less than 15%.
3. A foamed cellular material according to claim 1, having a degree of crystallinity of more than 30%.
4. A foamed cellular material according to claim 2, having a degree of crystallinity between 5 and 12%.
5. A foamed cellular material according to claim 3, having a degree of crystallinity between 30 and 40%.
6. A foamed cellular material according to any one of the preceding claims, having a bulk density of less than 100 kg/m³.
7. A foamed cellular material according to claim 6, having a degree of crystallinity of less than 15%.
8. A foamed cellular material according to claim 6, having a degree of crystallinity of more than 30%.
9. A foamed cellular material according to any one of claims 1 to 5, having a bulk density of 100 to 500 kg/m³.
10. A foamed cellular material according to any one of the preceding claims, obtained from polyester resins chosen among polyethylene terephthalate and copolyethylene terephthalates containing up to 20% of units derived from isophthalic acid.
11. A foamed cellular material according to any one of claims 1 to 9, obtained from polyester resins in the form of an alloy with polymers chosen among polyamides, polycarbonates and polycaprolactone, obtained by extruding the resin and the polymer in the presence of pyromellitic dianhydride and then upgrading the alloy at temperatures between 160° and 220°C.
12. A foamed cellular material according to claim 11, wherein the polyester resin is polyethylene terephthalate or copolyethylene terephthalate containing up to 20% of units derived from isophthalic acid in the form of an alloy with a polymer chosen among polyamides, polycarbonates and polycaprolactone used in an amount of up to 40% by weight on the total.
13. A foamed cellular material derived from aromatic polyester resins having a bulk density of less than 100 kg/m³, a

degree of crystallinity of less than 15% and the following tensile properties:

- maximum creep deformation between 10 and 60%;
- residual deformation after creep for 120 minutes between 10 and 30%;
- elastic recovery between 40 and 90%.

14. A foamed cellular material derived from aromatic polyester resins having a bulk density of 200 to 300 kg/m³, a degree of crystallinity of less than 15% and the following tensile properties:

- maximum creep deformation between 5 and 15%;
- residual deformation after creep for 120 minutes between 1 and 5%;
- elastic recovery between 75 and 90%.

15. A foamed cellular material from aromatic polyester resins having a bulk density of less than 100 kg/m³, a degree of crystallinity of more than 30% and the following dimensional thermostability and tensile properties:

- maximum shape permanence temperature: up to 150°C;
- maximum creep deformation: between 6 and 20%;
- residual deformation after creep for 120 minutes: between 2 and 10%;
- elastic recovery: between 50 and 80%.

16. A foamed cellular material according to claim 13, having a degree of crystallinity of 35 to 40% and a maximum dimensional stability temperature of up to 165°C.

17. A foamed cellular material derived from aromatic polyester resins having a bulk density of 100 to 300 kg/m³, a degree of crystallinity of 35 to 40% and a maximum dimensional stability temperature of up to 165°C.

18. A foamed cellular material according to any one of claims 11 to 15, obtained from polyester resins chosen among polyethylene terephthalate and copolyethylene terephthalate containing up to 20% of isophthalic acid units.

19. A foamed cellular material according to any one of claims 1 to 16, in the form of a sheet with a thickness of 1 to 3 mm or of a panel with a thickness of 10 to 50 mm.

20. A foamed cellular material according to any one of claims 1 to 17, obtained from aromatic polyester resins having an intrinsic viscosity of more than 0.8 dl/g, a melt viscosity of more than 2500 Pa · s and a melt strength of more than 8 cN.

21. A method for preparing the foamed cellular materials according to any one of claims 1 to 18, comprising the following steps:

- a) extrusion-foaming of a foamable aromatic polyester resin;
- b) cooling of the foamed material at the outlet of the extruder to a temperature and with cooling rates such that the material does not reach a degree of crystallinity of more than 15%;
- c) heating of the material, if it is not already at such a temperature at the outlet of the extruder after step b), to temperatures higher than the T_g of the material but lower than its melting point, with heating rates such that the crystallinity of the material remains lower than 15%;
- d) vacuum treatment of the thus heated material, keeping it under vacuum at a temperature which is higher than the T_g of the material but lower than the melting point for a time which is sufficient to achieve a decrease in the bulk density of the material of at least 30% with respect to the density of the material after step b);
- e) return of the material to atmospheric pressure.

22. A method according to claim 21, wherein the material, after vacuum treatment, is cooled to ambient temperature and kept under vacuum.

23. A method according to any one of claims 21 and 22, wherein the vacuum is between 10 and 50 mbar and the temperature of the vacuum heating is 90 to 180°C.

24. A method according to any one of claims 21 to 23, wherein the material is obtained from a polyester resin chosen

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between polyethylene terephthalate and copolyethylene terephthalate containing up to 20% of units derived from isophthalic acid.

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(19)



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- Vosa, Renato
81022 Casagiove (Caserta) (IT)
- Severini, Tonino
00034 Colleferro (Roma) (IT)
- Cobror, Sandro
86077 Pozzilli (Isernia) (IT)

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(71) Applicant: **SINCO RICERCHE S.p.A.**
28048 Verbania Pallanza (Verbania) (IT)

(74) Representative:
Gerbino, Angelo et al
c/o JACOBACCI & PERANI S.p.A.
Corso Regio Parco, 27
10152 Torino (IT)

(72) Inventors:
• **Al Ghatta, Hussain**
03014 Fiuggi (Frosinone) (IT)

(54) **Flexible polyester foams**

(57) A foamed cellular material which can be obtained from foamed aromatic polyester resins with a bulk density of 50 to 700 kg/m³ by heating in vacuum to temperatures which are higher than the T_g of the material and lower than its melting point. The foamed material, generally in the form of a sheet or panel, has high-level characteristics in terms of flexibility and dimensional thermostability depending on the degree of crystallinity after the vacuum treatment.

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EUROPEAN SEARCH REPORT

Application Number
EP 98 12 3226

DOCUMENTS CONSIDERED TO BE RELEVANT			
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A	PATENT ABSTRACTS OF JAPAN vol. 015, no. 345 (C-0864), 3 September 1991 & JP 03 134037 A (SEKISUI PLASTICS CO LTD), 7 June 1991 * abstract *	1	
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A	DATABASE WPI Section Ch, Week 9804 Derwent Publications Ltd., London, GB; Class A23, AN 98-037112 XP002105228 & JP 09 291166 A (KIRIN BREWERY KK) , 11 November 1997 * abstract *	1	
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The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 8 June 1999	Examiner Niaounakis, M
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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(71) Applicant: **SEKISUI KASEIHIN KOGYO
KABUSHIKI KAISHA**
25, 1-chome Minami Kyobate-cho
Nara-shi Nara 630(JP)

(72) Inventor: **Hayashi, Motoshige**
18-7, Gakuen Asahi-cho
Nara-shi, Nara(JP)
Inventor: **Amano, Norio**
1261-4 Tsutsui-cho
Yamato Koriyama-shi, Nara(JP)
Inventor: **Taki, Takeshi**
1-44-406 Kataokadal 3-chome, Kanmaki-cho
Kitakatsuragi-gun, Nara(JP)
Inventor: **Hirai, Takaaki**
28-1-B-110 Sanjo Hinoki-cho
Nara-shi, Nara(JP)

(74) Representative: **Pearce, Anthony Richmond**
MARKS & CLERK Alpha Tower Suffolk Street
Queensway Birmingham B1 1TT (GB)

(54) **Food container.**

(57) A food container is produced by laminating a non-foam film of a thermoplastic resin on at least one side of the foam sheet of a thermoplastic polyester resin having a degree of crystallinity of 15% or more to obtain a laminated sheet, and molding the laminated sheet into a container in such a manner that the non-foam film is positioned inside the container.

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FIELD OF THE INVENTION

This invention relates to a process for producing a thermoplastic polyester resin foam by extrusion, and also relates to a polyester resin foam product which gives fine cells uniformly formed at a high expansion ratio and does not cause the generation of colored contaminants in the foam even in continuous extrusion operation. It also relates to a thermoplastic polyester resin foam sheet excellent in thermoformability.

The polyester resin foam of the present invention is high in rigidity, though the foam has a low density and is lightweight. Further, the foam is excellent in heat resistance, chemical resistance, heat insulating properties and shock-absorbing properties and can be widely used. Particularly, the polyester resin foam sheet is suitable for use as a material which can be thermoformed into heat-resistant food containers.

BACKGROUND OF THE INVENTION

Thermoplastic polyester resins such as polyethylene terephthalate and polybutylene terephthalate are excellent in mechanical characteristics, heat resistance, chemical resistance and dimensional stability and are widely used in the fields of injection-molded articles, fibers and films. However, it is difficult that the thermoplastic polyester resins during melting are brought into such viscoelastic properties that foams can be obtained. Hence, a blowing agent is easily released during foam extrusion and it is difficult to obtain good foams wherein fine closed cells are uniformly formed. To solve this problem, there was proposed a method wherein diglycidyl esters are incorporated in aromatic polyesters in the foam extrusion of the aromatic polyesters [see, JP-B-61-48409 (the term "JP-B" as used herein means an examined Japanese patent publication)]. In the foam extrusion of thermoplastic polyesters, there was proposed a method wherein polyfunctional diglycidyl esters and polyfunctional carboxylic acid anhydrides are incorporated in thermoplastic polyesters to improve the melt viscosity of the thermoplastic polyesters [see, JP-A-59-210955 (the term "JP-A" as used herein means an "unexamined published Japanese patent application")].

The present inventors have been engaged in the production and study of extruded foams for many years and have had experience in that when the foam extrusion comprising a thermoplastic polyester in admixture with diglycidyl ester compounds is subjected to continuous long run, the resulting foam becomes discolored. The present inventors have continued to make the study and found that when pyromellitic dianhydride is mixed with a thermoplastic polyester without using any diglycidyl ester compound, the resulting foam is not colored and burned even when foam extrusion is continuously conducted over a long period of time.

The present inventors have further continued making the study and found that when compounds having two or more acid anhydride groups per molecule such as pyromellitic dianhydride and compounds of Group I, II or III metals of the Periodic Table are added to thermoplastic polyester resins, the viscoelasticity of the molten materials is improved and at the same time, there can be obtained foams having high tensile elongation and more finer cells.

JP-A-59-135237 (U.S. Patents 4,452,947 and 4,466,943, European Patent 0115162A) discloses that polyester resin foam sheets can be thermoformed into heat-resistant food containers which can be used in dual ovenable applications. However, the method disclosed therein has disadvantages in that since not only the melt viscosity is low when a polycarbonate is merely mixed, but carbon dioxide liberated from the polycarbonate is used as a blowing agent, expansion ratio is low, heat resistance is poor and the container cannot be removed with the bare hands when used for heating or cooking foods in microwave ovens.

The present inventors have found thermoplastic polyester resin foam sheets having a high expansion ratio, good heat insulating properties and excellent thermofoamability in the above-described study.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a process for producing a thermoplastic polyester resin foam which is highly expanded by adjusting viscoelastic properties during melting in the extrusion foaming of thermoplastic polyester resins.

It is another object of the present invention to provide a process for producing a thermoplastic polyester resin foam which does not cause the generation of colored contaminants therein even when long-term continuous operation is conducted in the extrusion foaming of thermoplastic polyester resins.

It is still another object of the present invention to provide a process for producing a thermoplastic polyester resin foam having uniform fine cells in the extrusion foaming of thermoplastic polyester resins.

It is another object of the present invention to provide a thermoplastic polyester resin foam excellent in tensile strength and tensile elongation in extrusion foaming.

It is still a further object of the present invention to provide a process for producing a thermoplastic polyester resin foam which is highly expanded and has excellent heat resistance by re-heating an extrusion-expanded thermoplastic polyester resin foam to carry out post-expansion.

It is another object of the present invention to provide an extruded foam sheet of a thermoplastic polyester resin, which is excellent in formability such as thermoformability.

It is still a further object of the present invention to provide a heat-resistant food container which is obtained by thermoforming an extruded foam sheet of a thermoplastic polyester resin and can be used in dual ovenable applications.

The present invention is intended to achieve the above-described objects and the essentials of the present invention resides in that:

- (1) a process for producing a thermoplastic polyester resin foam comprising melting a thermoplastic polyester resin, mixing the molten resin with a blowing agent and extruding the mixture into a low-pressure zone to carry out foaming, characterized in that a compound having two or more acid anhydride groups per molecule is added to the thermoplastic polyester resin;
- (2) a process for producing a thermoplastic polyester resin foam comprising melting a thermoplastic polyester resin, mixing the molten resin with a blowing agent and extruding the mixture into a low-pressure zone to carry out foaming, characterized in that a compound having two or more acid anhydride groups per molecule and a compound of a metal of Groups I, II or III elements of the Periodic Table are added to the thermoplastic polyester resin;
- (3) a process for producing a thermoplastic polyester resin foam comprising cooling a high-temperature thermoplastic polyester resin foam immediately after expansion to a temperature of not higher than the glass transition point of the resin to thereby bring its crystallinity to 30% or lower and then heating the polyester resin foam to 60° C or higher;
- (4) a thermoplastic polyester resin foam sheet which is an extruded foam sheet of a thermoplastic polyester resin and has a crystallinity of not higher than 20% and an molecular orientation ratio of 4.5 or below looking in a direction from the surface of the foam sheet; and
- (5) a food container prepared by bonding a non-foam film of a thermoplastic resin to at least one side of a thermoplastic polyester resin foam sheet to obtain a laminated sheet and thermoforming the sheet into a container in such a manner that the non-foam film is positioned inside.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1 to 3 are sectional views of means for carrying out re-heating according to present invention.

Figure 4 shows diagrammatically one embodiment of a means for continuously carrying out re-heating according to the present invention.

Figure 5 is a graph illustrating the results of Test Example 2.

Figure 6 shows a side view of a food container according to the present invention.

Figure 7 shows a planar view of a food container according to the present invention.

Figures 8, 9 and 10 are electron microscopic photographs which show the shapes of cells of the foams prepared in Examples 9, 12 and 17, respectively.

DETAILED DESCRIPTION OF THE INVENTION

In the production of the polyester resin foams of the present invention, extruders are used. Thermoplastic polyester resins are melted under an elevated pressure in the extruders and the molten resins are extruded through die into a low-pressure zone to produce foams.

In the production of the polyester resin foams of the present invention, compounds having two or more acid anhydride groups per molecule are added to thermoplastic polyester resins. By adding the compounds having two or more acid anhydride groups per molecule, the viscoelastic properties of the thermoplastic polyester resins during extrusion can be improved, whereby gasified blowing agents can be retained in the interiors of closed cells and uniformly dispersed fine cells can be formed using extruders.

It is believed that the compound having two or more acid anhydride groups per molecule is bonded to OH groups in the molecule chain of the thermoplastic polyester resin and crosslinking gently takes place, whereby the viscoelastic properties of the thermoplastic polyester resin during extrusion can be improved.

The term "viscoelastic properties during melting" can be confirmed by a phenomenon wherein the molten resin is swollen or shrunk from the outlet of the die when the molten resin is extruded through the die, and can be generally represented by a die swell ratio. The die swell ratio can be measured when a molten resin is extruded through a round orifice die having a circular section. Die swell ratio can be

determined by the following formula.

$$\text{Die swell ratio} = \frac{(\text{Diameter of extruded melt})}{(\text{Diameter of outlet of die})}$$

Die swell ratio is an important factor in extrusion foaming. It is preferred that die swell ratio is 2 to 5 in order to obtain foamed articles having a large sectional area and uniformly dispersed fine cells in particular.

In the present invention, a blend of a thermoplastic polyester resin and a compound having two or more acid anhydride groups is molten in an extruder, a blowing agent is generally injected into the molten blend and the resulting molten blend is extruded through the die of the extruder for foaming into a low-pressure zone to produce a foam.

In another embodiment of the present invention, a compound having two or more acid anhydride groups per molecule and further a compound of a metal of Group I, II or III elements of the Periodic Table are added to a thermoplastic polyester resin. In the same manner as that described above, the resulting blend is fed to an extruder to produce a foam. By adding a compound of a metal of Group I, II or III elements of the Periodic Table, there can be obtained a thermoplastic polyester resin foam having finer cells uniformly dispersed therein.

Thermoplastic polyester resins used in the present invention are linear polyesters of polycondensates of an aromatic dicarboxylic acid component and a diol component.

Examples of dicarboxylic acid components which can be used in the present invention include terephthalic acid, isophthalic acid, naphthalenedicarboxylic acid, diphenyl ether carboxylic acid, diphenyl sulfone dicarboxylic acid and diphenoxyethanedicarboxylic acid.

Examples of diol components which can be used in the present invention include ethylene glycol, trimethylene glycol, tetramethylene glycol, neopentyl glycol, hexamethylene glycol, cyclohexanedimethanol, tricyclodecanedimethanol; 2,2-bis(4- β -hydroxyethoxyphenyl)propane, 4,4-bis(β -hydroxyethoxy)diphenyl sulfone, diethylene glycol and 1,4-butanediol.

Polyethylene terephthalate, polybutylene terephthalate, polybutylene terephthalate elastomer, amorphous polyesters, polycyclohexane terephthalate, polyethylene naphthalate and mixtures thereof are preferably used as the polyesters comprising these dicarboxylic acid components and these diol components. Modified resins composed of at least 50% of these thermoplastic polyester resins can be used.

Any of aromatic acid anhydrides, cyclic aliphatic acid anhydrides, fatty acid anhydrides, halogenated acid anhydrides, etc. can be used as the compounds having two or more acid anhydride groups per molecule, so long as they have at least two acid anhydride groups per molecule. Further, mixtures thereof and modified compounds thereof can be used. Preferred examples of the compounds include pyromellitic dianhydride, benzophenonetetracarboxylic dianhydride, cyclopentanetetracarboxylic dianhydride, diphenyl sulfone tetracarboxylic dianhydride and 5-(2,5-dioxotetrahydro-3-furanyl)-3-methyl-3-cyclohexen-1,2-dicarboxylic dianhydride. Among them, pyromellitic dianhydride is more preferred.

The compounds having two or more acid anhydride groups per molecule are used in an amount of preferably 0.05 to 5.0 parts by weight per 100 parts by weight of the thermoplastic polyester resin. When the amount of the compound having two or more acid anhydride groups per molecule is less than 0.05 part by weight per 100 parts by weight of the thermoplastic polyester resin, an effect of improving the viscoelastic properties of the thermoplastic polyester resin during extrusion is not sufficient and good foam cannot be formed, while when the amount exceeds 5.0 parts by weight, the gelation of the molten material of the thermoplastic polyester resin proceeds and extrusion foaming cannot be effected.

Any of inorganic compounds and organic compounds can be used as the compounds of metals of Group I, II or III elements of the Periodic Table, so long as they have these metals as their constituent atoms. Examples of the inorganic compounds include potassium chloride, sodium chloride, sodium hydrogencarbonate, sodium carbonate, potassium carbonate, zinc carbonate, magnesium carbonate, calcium carbonate, aluminum carbonate, sodium oxide, potassium oxide, zinc oxide, magnesium oxide, calcium oxide, aluminum oxide and the hydroxides of these metals. Examples of the organic compounds include sodium stearate, potassium stearate, zinc stearate, magnesium stearate, calcium stearate, aluminum stearate, sodium montanate, calcium montanate, lithium acetate, sodium acetate, zinc acetate, magnesium acetate, calcium acetate, sodium caprylate, zinc caprylate, magnesium caprylate, calcium caprylate, aluminum caprylate, sodium myristate, zinc myristate, magnesium myristate, calcium myristate, aluminum myristate, calcium benzoate, potassium terephthalate, sodium terephthalate, sodium ethoxide and potassium

phenoxide. Among them, the compounds of Group I or II metals of the Periodic Table are preferred and the compounds of Group I metals are more preferred. By using the compounds of Group I, II or III metals, the cells of the resulting thermoplastic polyester resin foam are made finer and at the same time, an effect of increasing the viscoelasticity by the compound having two or more acid anhydride groups per molecule can be increased.

The compounds of Group I, II or III metals of the Periodic Table are used in an amount of 0.05 to 5.0 parts by weight per 100 parts by weight of the thermoplastic polyester resin. When the amount of the compound is less than 0.05 part by weight, effects of making the cells of the resulting foam finer and the efficiency of increasing the viscoelasticity by the compound having two or more anhydride groups are not sufficient, while when the amount exceeds 5 parts by weight, the resulting foam is colored and the viscosity of the molten thermoplastic polyester resin is not high enough.

Any of blowing agents can be used in the production of the thermoplastic polyester resin foams of the present invention, so long as they are easily vaporizable liquids or thermally decomposable chemicals. Easy vaporizable blowing agents such as inert gases, saturated aliphatic hydrocarbons, saturated alicyclic hydrocarbons, aromatic hydrocarbons, halogenated hydrocarbons, ethers and ketones are preferred. Examples of these easy vaporizable blowing agents include carbon dioxide, nitrogen, methane, ethane, propane, butane, pentane, hexane, methylpentane, dimethylbutane, methylcyclopropane, cyclopentane, cyclohexane, methylcyclopentane, ethylcyclobutane, 1,1,2-trimethylcyclopropane, trichloromonofluoromethane, dichlorodifluoromethane, monochlorodifluoromethane, trichlorotrifluoroethane, dichlorotetrafluoroethane, dichlorotrifluoroethane, monochlorodifluoroethane, tetrafluoroethane, dimethyl ether, 2-ethoxyethane, acetone, methyl ethyl ketone, acetylacetone, dichlorotetrafluoroethane, monochlorotetrafluoroethane, dichloromonofluoroethane and difluoroethane.

Usually, the blowing agent is injected into the molten blend of the thermoplastic polyester resin, the compound having two or more acid anhydride groups per molecule and other additives on the way of an extruder. The amount of the blowing agent to be injected is from 0.05 to 50% by weight based on the amount of the molten blend. When the amount of the blowing agent is less than 0.05% by weight, the resulting foam is not sufficiently expanded, while when the amount is more than 50% by weight, the gas of the blowing agent is not accommodated for foaming, but blows off and the foam cannot be formed into a desired shape. The preferred amount of the blowing agent is 0.1 to 30% by weight based on the amount of the molten blend.

In the production of the thermoplastic polyester resin foams of the present invention, stabilizer, expansion nucleating agent, pigment, filler, flame retarder and antistatic agent may be optionally added to the resin blend to improve the physical properties of the thermoplastic polyester resin foams and molded articles thereof.

In the production of the thermoplastic polyester resin foams of the present invention, foaming can be carried out by any of blow molding process and extrusion process using single screw extruder, multiple screw extruder and tandem extruder.

Dies used in the extrusion process or the blow molding process are flat die, circular die and nozzle die according to the shape of the desired foam.

In the production of the polyester resin foams of the present invention, the thermoplastic polyester resin can be mixed with the compound having two or more acid anhydride groups per molecule and other additives by any of the following methods.

(A) The thermoplastic polyester resin is mixed with the compound having two or more acid anhydride groups per molecule at a low temperature (e.g., a temperature of not higher than 150°C). (For example, the powder of the compound having two or more acid anhydride groups per molecule is stuck on the pellet of the thermoplastic polyester resin).

(B) The compound having two or more acid anhydride groups per molecule is previously melt-mixed with a thermoplastic resin, the mixture is pelletized and the pellet is mixed with the thermoplastic polyester resin (this thermoplastic resin may be the same as or different from the thermoplastic polyester resin, but is preferably one compatible with the thermoplastic polyester resin).

(C) The thermoplastic polyester resin is previously fed to an extruder hopper to melt it and the compound having two or more acid anhydride groups per molecule is fed through a feed opening provided at the cylinder of the extruder to effect mixing.

In any of the above mixing methods, the moisture content of the resin blend should be as small as possible and is reduced to preferably not higher than 200 ppm. It is preferred that the thermoplastic polyester resin is dried at a temperature of 60 to 180°C with hot air having a dew point of not higher than -20°C in a dehumidifying hot-air dryer for about 4 hours.

The present invention also relates to a process for producing a thermoplastic polyester resin foam, which comprises cooling a high-temperature thermoplastic polyester resin foam immediately after expansion to a temperature of not higher than the glass transition point of the resin to bring the crystallinity to 30% or below and then heating the foam to higher than 60°C.

Pre-expanded (primarily expanded) foam extruded through an extruder has only a low expansion ratio and usually a high density. The expansion ratio varies depending on the shapes of foams, but is about 5 times at most when the extruded foam is a sheet. In the present invention, the thus-obtained pre-expanded foam, while its temperature is high immediately after extrusion, is cooled to a temperature of not higher than the glass transition point of the polyester resin. The glass transition point of the polyester resin varies depending on the types of carboxylic acids and alcohols which constitute polyesters, but is generally in the range of 30 to 90°C. Hence, the foam is generally cooled to a temperature of not higher than 60°C.

When the pre-expanded foam is cooled, it is settled without having time to crystallize, and hence the crystallinity thereof is low. The crystallinity varies depending on the degree of cool. For example, the crystallinity varies depending on the type and temperature of cooling media and the contact conditions of the foam with the cooling media. When the pre-expanded foam prepared by extrusion is brought into directly contact with water at room temperature, the crystallinity thereof is several % to ten-odd %, generally not higher than 30%. However, when the pre-expanded foam prepared by extrusion is put into a mold to shape it, crystallinity becomes 30% or higher, since the foam is not cooled unless the mold is forcibly cooled. Particularly, the crystallinity of thick-wall pre-expanded foam becomes 30% or higher. Accordingly, when the pre-expanded foam is prepared by means of the extruder, the foam is allowed to proceed along a cooled mold to thereby cool it.

In order to conduct effectively the cooling of the pre-expanded foam, it is desirable that the foam has a large surface area in comparison with its volume. Namely, it is desirable that the foam is in the form of a sheet, if possible and its thickness is not more than 10 mm, preferably not more than 3 mm. When the sheet is cylindrical, a mandrel is put into the inside of the cylinder, the sheet is allowed to proceed along the mandrel which is cooled with water and the length of the mandrel should be as long as possible. On the other hand, when the sheet is a flat sheet, the sheet is put between a pair of rollers and allowed to proceed while cooling and at the same time, the rollers are cooled with water and the diameters of rollers should be as large as possible. In this way, the crystallinity of the pre-expanded foam is brought to 30% or below.

The foam is then re-heated to carry out post expansion (secondary expansion). For post expansion, the foam is heated to 60°C or higher. Any of heating means can be used. For example, heating may be conducted by conduction in contact with a heating plate. Alternatively, heating may be conducted by radiation, convection or high-frequency power. Any of heating media can be used, so long as polyester resins are not deteriorated by them. A preferred heating method is such that the pre-expanded foam is brought into contact with a heated metal or air or with steam or heated water.

The heating time for the post expansion is determined according to the properties of the resins, the shape and the type and temperature of the heating medium. Generally, when the temperature of the heating medium is low, heating time is prolonged, while when the temperature is high, heating time is shortened. Further, when the foam is thick-walled, heating time is prolonged, while when the foam is thin-walled, heating time is shortened.

It is preferred that a metal plate is heated to 60 to 200°C and the pre-expanded foam is brought into contact with the metal plate for 5 seconds or longer when the foam is heated by bringing it into contact with the metal plate. When the pre-expanded foam is heated by bringing it into contact with air, it is preferred that the foam is put into an oven, the temperature within the oven is elevated to 100 to 230°C and the foam is heated for 10 seconds to 5 minutes. It is desirable that when the foam is heated by the metal plate or air, the foam is left to stand for at least 24 hours, usually about 3 days after the pre-expansion and then is subjected to the post expansion without conducting post expansion immediately after pre-expansion.

On the other hand, when the pre-expanded foam is heated by bringing it into contact with steam or hot water, post expansion can be carried out immediately after pre-expansion. In this case, the temperature of steam or water is 60 to 125°C and contact time is 10 seconds to 5 minutes.

The polyester resin foam can be brought into contact with steam or water by various methods. For example, the foam 1 may be immersed in heated water 2 as shown in Fig. 1. In Fig. 1, a numeral 8 means a burner. In another embodiment, a metal gauze 3 is placed above the surface of heated water and the foam 1 is placed on the metal gauze 3 and is brought into contact with steam 4 which is evaporated from water 2 as shown in Fig. 2. In other embodiment, pressurized steam 4 is blown into a container 9 containing the foam 1 as shown in Fig. 3.

It is preferred that the foam is placed in a mold and molded into a desirable shape when the foam is to be heated by bringing it into contact with water or steam. When a mold is used, water or steam is

introduced into the mold to thereby bring the foam into directly contact with water or steam.

When the polyester resin foam is heated to 60°C or higher by bringing it into contact with water or steam in the manner described above, the foam is post-expanded to form a foam having a low density. Generally, highly post expansion can be easily conducted by heating with water or steam rather than air. Further, steam is more preferable than water. When heating is conducted with water or steam, the post expansion ratio is at least 1.3 though it is lower than the pre-expansion ratio, and it is possible that the ratio is 4 or more. In addition thereto, expansion can be uniformly carried out and the resulting post-expanded foam has fine, uniform cells. In this way, a low-density foam of good quality can be obtained.

Thus, when the pre-expanded foam is heated, not only a low-density foam can be readily obtained, but the post-expanded foam can be rendered to have a crystallinity of 15% or more. A foam having a crystallinity of 15% or more is a foam which is very excellent in heat resistance in a heating atmosphere and can be used for heat-resistant food containers, heat insulating materials, etc.

Further, the melt viscosity, die swell ratio, etc. of the thermoplastic polyester resins are adjusted in the process of the present invention to produce extrusion foam sheets. The extrusion foam sheets of the thermoplastic polyester resins have a density of preferably not higher than 0.7 g/cm³, more preferably not higher than 0.5 g/cm³. When the density exceeds 0.7 g/cm³, heat insulating properties, lightweight properties and cushioning properties as foam sheet are lost. It has been found that the extrusion foam sheets having a crystallinity of not higher than 20% and a molecular orientation ratio of not higher than 4.5 in the direction of face of foam sheet are preferred from the viewpoint of thermoformability. It is difficult to lower the crystallinity through the thickness, since the extrusion foam sheet immediately after extrusion has heat insulating properties. However, post thermoformability can be improved by lowering the molecular orientation ratio to a specific value or below.

The molecular orientation ratio of the extrusion foam sheet looking in a direction from the surface of the foam sheet can be adjusted to 4.5 or below by controlling expansion in the direction of extrusion and in the direction crossing the extrusion direction. As a preferred method therefor, there is generally used a method using a circular die and a cylindrical mandrel. Namely, expansion in the direction of extrusion can be controlled by the ratio of the average flow rate of a foamed resin to a take-off speed in the direction of extrusion at the outlet gap of the circular die, and expansion in the direction crossing the extrusion direction can be controlled by the ratio (hereinafter referred to as blow-up ratio) of the diameter of the outlet of the circular die to the outer diameter of the mandrel.

Crystallinity is determined from quantity of heat of cold crystallization and quantity of heat of fusion in heating by heat-flux DSC (differential scanning calorimetry) in the measurement of heat of transition according to JIS-K-71222 (Method for measuring heat of transition of plastics). Namely, crystallinity is determined by the following equation.

$$\text{Crystallinity (\%)} = \frac{(\text{Quantity of heat of fusion per mol}) - (\text{quantity of heat of cold crystallization per mol})}{\text{Quantity of heat of fusion per mol of perfect crystallized resin}} \times 100$$

Crystallinity was measured by using differential scanning calorimeter DSC 200 manufactured by Seiko K.K. For the quantity of heat of perfect crystal fusion of polyethylene terephthalate, there was used 26.9 kJ/mol from Kobunshi Deta Handobukku (published by Baifukan KK).

Molecular orientation ratio in the direction of face of foam sheet is the ratio between the maximum value of intensity of microwave transmitted through foam sheet and the minimum value thereof when the surface of foam sheet is perpendicularly irradiated with a polarizer (manufactured by Kanzaki Paper Mfg. Co., Ltd.).

Further, food containers can be produced by bonding a non-foam film of a thermoplastic resin to at least one side of the extrusion foam sheet of the thermoplastic polyester resin according to the present invention to form a laminated sheet and thermoforming it into a food container in such a manner that the non-foam sheet is positioned inside.

Examples of the thermoplastic resin which constitutes the non-foam film include thermoplastic polyester resins, liquid crystal polyester resins, polyolefin resins, polyamide resins, polyvinyl chloride resins, polyacrylonitrile resins, polyvinylidene chloride resins and ethylene-vinyl alcohol copolymers.

Non-foam film to be bonded may be composed of a single-layer film or multi-layer film. The non-foam film may be bonded to both sides of the foam sheet. The thickness of the non-foam film layer is 10 to 500 microns and the thickness of the sheet layer of the expanded polyester resin is thicker, i.e., generally not more than 5 mm. It is preferred that the thickness of the foam sheet layer is 2 to 500 times that of the non-foam film layer.

The non-foam film can be laminated onto the foam sheet by using a plurality of extruders. More particularly, a thermoplastic polyester resin is fed to an extruder and an expandable polyester resin is extruded therethrough. Separately, a thermoplastic resin is fed to other extruder and a non-expandable resin is extruded therethrough. These resins are guided to the same one die and combined together in the die to prepare a laminated sheet. In another embodiment, the resins extruded through each extruder are fed to separate dies to prepare a foam sheet and a film, respectively. They are put upon each other and pressed through rollers to prepare a laminated sheet.

In a still other embodiment, the foam sheet and the non-foam sheet are separately prepared and separately wound up into rolls. They are laminated onto each other, while unwinding, and passed through a pair of rollers to thereby laminate them. The temperature of the roller on the side of the foam sheet is preferably low, for example, room temperature to prevent polyester resin from being crystallized. On the other hand, the roller on the side of the non-foam film is kept preferably at a high temperature so as to soften the surface of the film.

The laminated sheet is re-heated and thermoformed into a container. The thermoforming is carried out by using a molding die. The die may be composed of a male mold and a female mold, but may be composed of either one of them. When a die composed of both molds is used, molding can be carried out merely by putting the laminated sheet between both molds and pressing it. However, when either one of molds is used, air present between the sheet and the mold is removed, or the sheet is pressurized from the upper side thereof and pressed. The non-foam film is so arranged that the film is positioned inside the container.

The heating temperature at which the sheet is molded into a container is determined according to the thermoplastic polyester resin constituting the foam sheet and the thermoplastic resin constituting the non-foam film. The expansion ratio of the foam sheet is increased or decreased by the heating temperature. Accordingly, even when a foam sheet having the same thickness is used, a difference in the thickness of the laminated sheet is caused. Further, the crystallinity of the foam sheet is accelerated depending on the heating temperature and the heating time.

If the foam sheet by extrusion, which is composed of a thermoplastic polyester resin, has a crystallinity of 15% or more, it is excellent in heat resistance in a heating atmosphere in air. However, in the case that it is exposed to heated steam of 100 °C or higher, since the film wall thickness of first layer cells on the surface is thin, the first layer cells are re-swollen. Further, in the case that it is used for a food container to heat foodstuffs such as soup and gratin, the first layer cells are re-swollen, whereby juices from the foodstuffs were likely penetrated into the cells. On the other hand, since in the present invention a non-foam film is bonded such that it is positioned inside the container, the re-swelling by heated steam or hot water and the penetration of juices from the foodstuffs into the cells can be prevented.

The following Examples, Comparative Examples and Test Examples are provided to illustrate the present invention, but are not to be construed as limiting the present invention in any way.

TEST EXAMPLE 1

An experiment was carried out to examine the effects of the addition of the compound having two or more acid anhydride groups per molecule to the thermoplastic polyester resin on viscoelastic properties during melting.

(1) Test-1

Polyethylene terephthalate (PET 9902, a product of Eastman Kodak Company) was dried at 160 °C with hot air having a dew point of -30 °C in a dehumidifying dryer for 4 hours. 1 kg of the resulting dried material was mixed with 5 g of pyromellitic dianhydride (a product of Chemische Werke Hüls AG). The blend was fed to the hopper of a single screw extruder (diameter of screw: 40 mm, L/D: 30, manufactured by Sekisui Koki K.K.) equipped with a cylindrical channel die (diameter: 5 mm, L/D: 1.6). The molten blend was extruded through the cylindrical channel die at an extrusion rate of 7 kg/Hr under the following production conditions to carry out molding.

Production conditions by the single screw extruder

Temperature of feed zone of extruder:	270 ° C
Temperature of compression zone of extruder:	280 ° C
Temperature of melting zone of extruder:	270 ° C
Temperature of die:	270 ° C
Number of revolutions of screw of extruder:	32 rpm

(2) Test-2 (control)

The extrusion of polyethylene terephthalate was carried out in the same manner as in Test-1 except that pyromellitic dianhydride was omitted.

(3) Test results

Die swell ratio of extrudate and the melt viscosity of the molten resin in the single screw extruder are shown in Table 1.

Table 1

Effect of the addition of pyromellitic dianhydride to polyethylene terephthalate on melt viscosity and die swell ratio				
Test No.	Amount of Polyethylene Terephthalate (g)	Amount of Pyromellitic Dianhydride (g)	Die Swell Ratio	Melt Viscosity (poise)
1	1000	5	3.3	2.8×10^4
2	1000	0	1.2	0.8×10^4

(4) Discussion

It is clear from Table 1 that when pyromellitic anhydride is added to polyethylene terephthalate, die swell ratio of extrudate is increased and the melt viscosity of the molten resin in extrusion is also increased.

EXAMPLE 1

10 kg of polyethylene terephthalate (PET 9902, a product of Eastman Kodak Company) was dried in a dehumidifying dryer (160 ° C with hot air having a dew point of -30 ° C) for 4 hours and then mixed with 20 g of pyromellitic dianhydride (Chemische Werke Hüls AG) and 60 g of talc (expansion nucleating agent) in a tumbling mixer. The mixture was fed to the hopper of a single screw extruder (diameter of screw: 40 mm, L/D: 30, bore of nozzle die: 5 mm) and melt-mixed. Isopentane (blowing agent) was injected into the molten mixture in an amount of 2.2% by weight. The molten mixture was extruded through the nozzle die under following production conditions into air to produce a rod-shaped foam.

Production conditions with single screw extruder

Temperature of feed zone of extruder:	273 to 282 °C
Temperature of compression zone of extruder:	280 to 290 °C
Temperature of melting zone of extruder:	271 to 290 °C
Temperature of extruder head:	280 to 290 °C
Number of revolutions of screw of extruder:	32 rpm
Extrusion rate:	7 to 8 kg/hr

The expansion ratio and diameter of the foam are shown in Table 2.

EXAMPLE 2

The procedure of Example 1 was repeated except that the amount of pyromellitic dianhydride was 30 g and isopentane was injected into the molten mixture in an amount of 2.5% by weight to produce a rod-shaped foam.

The expansion ratio and diameter of the foam are shown in Table 2.

EXAMPLE 3

The procedure of Example 1 was repeated except that the amount of pyromellitic dianhydride was 40 g and isopentane was injected into the molten mixture in an amount of 2.6% by weight to produce a rod-shaped foam.

The expansion ratio and diameter of the foam are shown in Table 2.

COMPARATIVE EXAMPLE 1Effect (1) of the use of pyromellitic dianhydride

The procedure of Example 1 was repeated except that pyromellitic dianhydride was omitted and isopentane was injected into the molten mixture in an amount of 2.7% by weight to produce a rod-shaped foam.

The expansion ratio and diameter of the foam are shown in Table 2.

COMPARATIVE EXAMPLE 2Effect (2) of the use of pyromellitic dianhydride

The procedure of Example 1 was repeated except that 50 g of phthalic anhydride was used in place of 20 g of pyromellitic dianhydride and isopentane was injected into the molten mixture in an amount of 2.7% by weight to produce a rod-shaped foam.

The expansion ratio and diameter of the foam are shown in Table 2.

Table 2

Example No.	Amount of Pyromellitic Dianhydride (g)	Amount of Isopentane (%)	Rod-shaped Foam		
			Density (g/cm ³)	Expansion Ratio (times)	Diameter (mm)
Example 1	20	2.2	0.35	4.0	21
Example 2	30	2.5	0.18	7.8	27
Example 3	40	2.6	0.13	10.8	30
Comp. Ex. 1	-	2.7	0.76	1.8	9
Comp. Ex. 2	-	2.7	0.70	2.0	11

Discussion:

It is clear from Table 2 that in Examples 1 to 3 wherein pyromellitic dianhydride is used, expansion ratios are 4 to 10, the diameters of the rod-shaped foams are increased to 4 to 6 times the size of the nozzle die and the increasing ratio thereof is in proportion to the increase in the amount of isopentane injected.

In Comparative Examples 1 and 2 wherein pyromellitic anhydride is omitted, expansion ratios are about 2, though isopentane (blowing agent) is used in an amount larger than that in Examples 1 to 3, and the diameters of the rod-shaped foams are about twice as large as the bore of the nozzle die. Accordingly, both the expansion ratio and the diameter are smaller than those of Examples 1 to 3.

These effects are thought to be due to the fact that when pyromellitic dianhydride is not used, the blowing agent isopentane is released from the foam in expansion molding, while when pyromellitic dianhydride is used in expansion molding, the melt viscosity of the thermoplastic polyester is increased, whereby gaseous isopentane (blowing agent) is not allowed to be released from the foam.

EXAMPLE 4

In the procedure of Example 3, the expansion molding operation was continuously carried out for 24 hours. No change for the rod-shaped foam was observed.

EXAMPLE 5

In the procedure of Example 3, the expansion molding operation was carried out for 5 hours and the operation was then stopped for 19 hours. Thereafter, operation and stopping were repeated five times in a 24 hour cycle.

In any case, there could be obtained a rod-shaped foam, which was neither colored nor contaminated within 30 minutes from the commencement of the operation.

COMPARATIVE EXAMPLE 3

In Example 3, diglycidyl terephthalate (Blemmer®, a product of Nippon Oil & Fats Co., Ltd) was used in place of pyromellitic anhydride and isopentane was injected into the molten mixture in such an amount as to give a 4 g/100 g mixture. In the same manner as in Example 5, the operation was carried out.

In the operation after the third operation, it took 90 minutes or longer until there could be obtained a rod-shaped foam which was neither colored nor contaminated. In the fifth operation, the foam was discolored yellow and contaminated with black matters after 4 hours from re-operation.

EXAMPLE 6

The procedure of Example 1 was repeated except that 50 g of cyclopentanetetracarboxylic acid dianhydride was used in place of 20 g of pyromellitic dianhydride to produce a rod-shaped foam.

The expansion ratio of the foam was 4 and the diameter thereof was 20 mm.

EXAMPLE 7

The procedure of Example 1 was repeated except that 50 g of benzophenonetetracarboxylic acid dianhydride was used in place of 20 g of pyromellitic dianhydride to produce a rod-shaped foam.

The expansion ratio of the foam was 4.5 and the diameter thereof was 21 mm.

EXAMPLE 8

In Examples 6 and 7, the operation was carried out in the same manner as in Example 5.

Within 30 minutes from the commencement of the operation, there could be obtained a rod-shaped foam which was neither colored nor contaminated in any case.

EXAMPLES 9 to 17

Polyethylene terephthalate given in Table 3 was dried with hot air having a dew point of -30°C at 160°C in a dehumidifying dryer for 4 hours. 100 parts by weight of the dried polyethylene terephthalate, pyromellitic dianhydride in an amount given in Table 3, a metallic compound given in Table 3 and 0.6 part by weight of talc (expansion nucleating agent) were mixed in a tumbling mixer. The mixture was fed to the hopper of a single screw extruder (diameter of screw: 40 mm, L/D: 30) equipped with a nozzle die (bore: 5 mm). 2.0% by weight of n-pentane was injected into the molten mixture. The molten mixture was extruded under the following conditions to obtain a rod-shaped foam.

Temperature of feed zone of extruder:	268 to 280°C
Temperature of compression zone of extruder:	285 to 290°C
Temperature of melting zone of extruder:	275 to 285°C
Temperature of extruder head:	275 to 285°C
Temperature of extruder die:	275 to 285°C
Number of revolutions of screw:	32 rpm

The expansion ratios of the foams and the state of cells are shown in Table 3.

Fig. 8 is an electron microscopic photograph showing the state of cells of the foam prepared in Example 9, which is enlarged about 25 times. The cells shown in Fig. 8 were small.

Further, Figs. 9 and 10 are electron microscopic photographs showing the states of cells of the foams prepared in Examples 12 and 17, respectively, which are enlarged about 25 times. The cells of the foam prepared in Example 17 were slightly larger than those in Example 12.

COMPARATIVE EXAMPLE 4

The procedure of Example 9 was repeated except that pyromellitic dianhydride and the metallic compound were omitted to produce a rod-shaped foam.

The expansion ratio of the foam and the state of cells are shown in Table 3.

EXAMPLES 18 to 20

The procedure of Example 9 was repeated except that polyester resins, acid anhydrides and metallic compound given in Table 4 were used to obtain foams.

The expansion ratios of the foams and the state of cells are shown in Table 4.

COMPARATIVE EXAMPLE 5

The procedure of Example 9 was repeated except that polyethylene terephthalate and diglycidyl terephthalate given in Table 4 were used and the metallic compound was omitted to obtain a foam.

The expansion ratio of the foam and the state of cells are shown in Table 4.

EXAMPLE 21

Polyethylene terephthalate given in Table 5 was dried with hot air having a dew point of -30°C at 160°C in a dehumidifying dryer for 4 hours. 100 parts by weight of the dried polyethylene terephthalate, 0.5 part by weight of pyromellitic dianhydride, 0.1 part by weight of sodium carbonate and 0.6 part by weight of talc (expansion nucleating agent) were mixed in a tumbling mixer. The mixture was fed to the hopper of a single screw extruder (diameter of screw: 65 mm, L/D: 35) equipped with a cylindrical mandrel (bore: 205 mm, L/D: 1.5) and a circular die (bore: 60 mm, gap: 0.65 mm). 1.7% by weight of butane was injected into the molten mixture. The molten mixture was extruded through the circular die under the following conditions. The extrudate was taken off by a cylindrical mandrel and molded. A part of the resulting cylindrical foam was cut open and the resulting foam sheet was wound up.

15

20

Temperature of feed zone of extruder:	280 °C
Temperature of compression zone of extruder:	290 °C
Temperature of melting zone of extruder:	280 °C
Temperature of extruder head:	280 °C
Temperature of extruder die:	270 °C
Injection pressure of blowing agent:	80 kg/cm ²
Extrusion pressure (head):	115 kg/cm ²
Number of revolutions of screw:	30 rpm
Extrusion rate:	24 kg/hr

The expansion ratio of the foam sheet, the state of cells, tensile strength at 23°C and tensile elongation at break at 23°C are shown in Table 5.

COMPARATIVE EXAMPLE 6

The procedure of Example 21 was repeated except that diglycidyl terephthalate and sodium montanate in amounts given in Table 5 were used and pyromellitic dianhydride and sodium carbonate were omitted. The resulting foam sheet was wound up.

The expansion ratio of the foam sheet, the state of cells, tensile strength at 23°C and tensile elongation at break at 23°C are shown in Table 5.

COMPARATIVE EXAMPLE 7

The procedure of Example 21 was repeated except that diglycidyl terephthalate given in Table 5 was used, 0.9% by weight of butane was injected, extrusion was carried out under the following conditions and sodium carbonate was omitted. The resulting foam sheet was wound up.

40

45

50

Temperature of feed zone of extruder:	280 °C
Temperature of compression zone of extruder:	290 °C
Temperature of melting zone of extruder:	280 °C
Temperature of extruder head:	285 °C
Temperature of extruder die:	275 °C
Injection pressure of blowing agent:	40 kg/cm ²
Extrusion pressure (head):	90 kg/cm ²
Number of revolutions of screw:	25 rpm
Extrusion rate:	24 kg/hr

The extrusion ratio of the foam sheet, the state of cells, tensile strength at 23°C and tensile elongation at break at 23°C are shown in Table 5.

55

Table 3

Expansion ratio of foam and state of cells (Examples 9 to 17, Comparative Example 4)

Example No.	Composition of Materials						Foam	
	Polyethylene Terephthalate		Acid Anhydride		Metallic Compound		Expansion Ratio (times)	State of Cells
	Trade Name	Amount	Compound Name	Amount	Compound Name	Amount		
Example 9	PET 9902	100	pyromellitic dianhydride	0.5	sodium carbonate	0.3	15	small
Example 10	PET 9902	100	"	0.5	"	0.1	14	small
Example 11	PET 9902	100	"	0.3	"	0.1	10	small
Example 12	PET 9902	100	"	0.5	zinc stearate	0.1	9	medium
Example 13	PET 9902	100	"	0.5	calcium carbonate	0.1	12	medium
Example 14	PET 9902	100	"	0.5	aluminum stearate	0.1	9	medium
Example 15	TR 4550 BH	100	"	0.5	sodium carbonate	0.17	14	small
Example 16	TR 8510	100	"	0.25	"	0.08	14	small
Example 17	PET 9902	100	"	0.3	-	-	9	large
Comp. Ex. 4	PET 10388	100	-	-	-	-	2	large

Note: PET 9902 and PET 10388 manufactured by Eastman Kodak Company.
 TR 4550 BH and TR 8510 manufactured by Teijin Limited.
 Sodium carbonate manufactured by Toosh Corporation.
 Pyromellitic dianhydride manufactured by Chemische Werke Huls AG.

Table 4

Expansion ratio of foam and state of cells (Examples 18 to 20, Comparative Example 5)

Example No.	Composition of Materials						Foam			
	Polyester Resin Trade Name	Amount	Acid Dianhydride Compound Name	Amount	Epoxy Compound Compound Name	Amount	Metallic Compound Name	Amount	Expansion Ratio (times)	State of Cells
Example 18	TR 8580	100	cyclopentane-tetracarboxylic dianhydride	0.5	-	-	sodium carbonate	0.1	8	small
Example 19	TR 8580	100	benzophenone-tetracarboxylic dianhydride	0.5	-	-	"	0.17	9	medium
Example 20	XD 470	100	pyromellitic dianhydride	0.3	-	-	"	0.1	12	small
Comp. Ex. 5	TR 8580	100	-	-	diglycidyl terephthalate	0.5	-	-	8	medium

Note: TR 8580 manufactured by Teijin Limited.

XD 478 (MI: 3.0, 235°C) for polybutylene terephthalate, manufactured by Polyplastic Co., Ltd.

Pyromellitic dianhydride manufactured by Huls Japan Limited.

Sodium carbonate manufactured by Tosoh Corporation.

Table 3

Expansion ratio of foam, state of cells and tensile strength (Example 21, Comparative Examples 6 and 7)

Example No.	Composition of Materials					Foam Sheet		
	Polyethylene Terephthalate Trade Name Amount	Pyromellitic Dianhydride (amount)	Diglycidyl Terephthalate (amount)	Sodium Montanate Carbonate (amount)	Sodium Carbonate (amount)	Expansion Ratio (times)	State of Cells	Tensile Strength at Break at 23°C (kg/cm ²)
Example 21	PET 9902 100	0.5	-	-	0.1	6	medium	63.6
Comp. Ex. 6	PET 10388 100	-	0.3	0.1	-	6	medium	39.3
Comp. Ex. 7	TR 8580 100	0.2	0.6	-	-	3	medium	81.5
								116.6
								64.3
								53.3

Note: PET 9902 and PET 10388 manufactured by Eastman Kodak Company.

TR 8580 manufactured by Teijin Limited.

Pyromellitic dianhydride by Chemische Werke Huls AG.

Diglycidyl terephthalate: Blemmer® DGT manufactured by Nippon Oil & Fats Co., Ltd.

Sodium carbonate manufactured by Tosoh Corporation.

TEST EXAMPLE 2

Test Sample: Foam sheets prepared in Examples 21 and Comparative Example 6

- 5 Test method: Dynamic visco-elastometer (manufactured by Toyo Seiki Seisakusho, Ltd.) was used. Complex elastic modulus of test samples [5 mm (width) × 21 mm (length) × 1.5 mm (thickness)] was measured under the following conditions.

Frequency for measurement: 10 Hz
 Heating rate: 3 °C/min
 10 Distance between clamps: 15 mm

The results are shown in Fig. 5.

Discussion:

- 15 Complex elastic modulus of the foam sheet of Example 21 is higher than that of the foam sheet of Comparative Example 6. Hence, it can be understood that the heat resistance of the foam sheet obtained by using pyromellitic dianhydride and sodium carbonate is high.

The process for producing the thermoplastic polyester resin foam by re-heating is illustrated by means of the following Examples and Comparative Examples. Parts and percent given below are by weight unless
 20 otherwise stated.

EXAMPLE 22

Pre-expansion (primary expansion):

- 25 TR8580 (trade name, a product of Teijin Limited) was used as polyethylene terephthalate (hereinafter referred to as PET).

PET was placed in a dehumidifying dryer and dried at 160 °C for 4 hours while circulating hot air having a dew point of -30 °C. 100 parts of PET, 0.6 part of talc, 0.35 part of pyromellitic dianhydride and 0.1 part of
 30 sodium carbonate were thoroughly mixed in a tumbling mixer. The mixture was fed to an extruder (diameter of screw: 65 mm, L/D: 35) and thoroughly mixed at a screw revolution number of 25 rpm and at a barrel temperature of 270 to 290 °C. 1.3 parts of butane as a blowing agent per 100 parts of the mixture was introduced into the mixture under pressure on the way of the barrel. PET containing the blowing agent was extruded through the circular die into air to produce a tube. The die had a circular die gap of 0.4 mm and a
 35 bore of 60 mm and was kept at 270 to 285 °C. PET extruded into air was expanded and the tube as extruded was taken off while bringing it into contact with the outer surface of a cylindrical mandrel. The mandrel had an outer diameter of 205 mm and cooling water at 30 °C was circulated inside the mandrel so that the PET foam was quenched. The quenched PET foam was cut open and the resulting flat foam sheet was wound up and referred to as pre-expanded foam sheet (primarily expanded foam sheet). The foam
 40 sheet was 643 mm in width and had an apparent density (hereinafter referred to simply as density) of 0.26 g/cm³, a thickness of 1.5 mm and a crystallinity of 9%.

Post-expansion (secondary expansion):

- 45 A piece of 100 mm × 100 mm was cut off from the above pre-expanded foam sheet and subjected to post-expansion. The post expansion was carried out by immersing the piece in warm water at 63 °C for 5 minutes as shown in Fig. 1. The thickness was expanded from 1.5 mm to 2.1 mm. The ratio V_2/V_1 of the volume (V_2) of the post-expanded foam sheet to the volume (V_1) of the pre-expanded foam sheet was 1.37. The post-expanded foam sheet had a density of 0.19 g/cm³ and a crystallinity of 9%. The post-expanded
 50 foam sheet was finely expanded and found to be a good foam.

EXAMPLE 23

- The same pre-expanded foam sheet as that obtained in Example 22 was used and post expansion was
 55 carried in the same way as in Example 22 except that the temperature of warm water was 83 °C and immersion was conducted for 5 minutes.

There was obtained a post-expanded foam sheet which had a thickness of 3.02 mm, a density of 0.13 g/cm³ and a crystallinity of 10%. The ratio V_2/V_1 was 2.00. The foam sheet was finely, uniformly expanded,

had a low density and was found to be a good foam.

EXAMPLE 24

The same pre-expanded foam sheet as that obtained in Example 22 was used and post expansion was carried out by bringing the sheet into contact with steam as shown in Fig. 2. Namely, post expansion was carried out by bringing the sheet into contact with steam at 62 °C for 5 minutes.

There was obtained a post-expanded foam sheet which had a thickness of 2.51 mm and a density of 0.16 g/cm³. The ratio V_2/V_1 was 1.63.

EXAMPLE 25

The procedure of Example 24 was repeated except that the temperature of steam for post expansion was 75 °C.

There was obtained a post-expanded foam sheet which had a thickness of 2.73 mm and a density of 0.14 g/cm³. The ratio V_2/V_1 was 1.86.

EXAMPLE 26

The procedure of Example 24 was repeated except that the temperature of steam was 100 °C and the contact time was 0.5 minute in the post expansion.

There was obtained a post-expanded foam sheet which had a thickness of 2.78 mm, a density of 0.14 g/cm³ and a crystallinity of 10%. The ratio V_2/V_1 was 1.86.

EXAMPLE 27

The procedure of Example 26 was repeated except that post expansion was carried out by bringing the sheet into contact with steam at 100 °C for 2 minutes as shown in Fig. 2.

There was obtained a post-expanded foam sheet which had a thickness of 3.92 mm, a density of 0.10 g/cm³ and a crystallinity of 16%. The ratio V_2/V_1 was 2.60.

EXAMPLE 28

The procedure of Example 26 was repeated except that post expansion was carried out by bringing the sheet into contact with steam at 100 °C for 5 minutes.

There was obtained a post-expanded foam sheet which had a thickness of 5.63 mm, a density of 0.065 g/cm³ and a crystallinity of 26%. The ratio V_2/V_1 was 3.77.

EXAMPLE 29

The procedure of Example 26 was repeated except that post expansion was carried out by bringing the sheet into contact with steam at 100 °C for 7 minutes.

There was obtained a post-expanded foam sheet which had a thickness of 5.96 mm and a density of 0.065 g/cm³. The ratio V_2/V_1 was 4.00.

EXAMPLE 30

Post expansion was carried out in the same manner as in Example 29 by bringing the sheet into contact with steam at 100 °C for 7 minutes except that post expansion was carried out by placing a pre-expanded foam of 200 mm × 280 mm in an aluminum mold of 210 mm × 290 mm × 5 mm.

There was obtained a post-expanded foam sheet which had a thickness of 5.00 mm and a density of 0.078 g/cm³. The ratio V_2/V_1 was 3.33. The sheet obtained was a flat foam sheet.

EXAMPLE 31

The same pre-expanded foam sheet as that obtained in Example 22 was used and post expansion was carried out by blowing pressurized steam as shown in Fig. 3. Namely, post expansion was carried by bringing the sheet into contact with steam at 110 °C for 3 minutes.

There was obtained a post-expanded foam sheet which had a thickness of 3.41 mm and a density of 0.11 g/cm³. The ratio V_2/V_1 was 2.36.

EXAMPLE 32

The procedure of Example 31 was repeated except that post expansion was carried out by bringing the sheet into contact with steam at 120 °C for 0.5 minute.

There was obtained a post-expanded foam sheet which had a thickness of 3.00 mm and a density of 0.13 g/cm³. The ratio V_2/V_1 was 2.00.

EXAMPLE 33

Pre-expansion was carried out in the same manner as in Example 22 except that carbon dioxide was used as the blowing agent in place of butane and the amount of carbon dioxide was 1.1 parts. The resulting pre-expanded foam sheet was 643 mm in width and had a density of 0.26 g/cm³, a thickness of 1.5 mm and a crystallinity of 9%.

Post expansion was carried out in the same manner as in Example 28 to obtain a post-expanded foam sheet which had a thickness of 3.00 mm and a density of 0.13 g/cm³. The ratio V_2/V_1 was 2.00.

EXAMPLE 34

The procedure of Example 22 was repeated except that post expansion was carried out by using hot air at 80 °C in place of warm water at 63 °C and bringing the sheet into contact with hot air for 5 minutes to obtain a post-expanded foam sheet.

The post-expanded foam sheet was 2.1 mm in thickness and had a density of 0.19 g/cm³ and a crystallinity of 10%. The ratio V_2/V_1 was 1.37.

EXAMPLE 35

The procedure of Example 34 was repeated except that the temperature of hot air in the post expansion was 100 °C to obtain a post-expanded foam sheet.

The post-expanded foam sheet had a thickness of 2.6 mm, a density of 0.15 g/cm³ and a crystallinity of 10%. The ratio V_2/V_1 was 1.73.

EXAMPLE 36

The procedure of Example 34 was repeated except that the temperature of hot air in the post expansion was 110 °C to obtain a post-expanded foam sheet.

The post-expanded foam sheet had a thickness of 2.8 mm, a density of 0.14 g/cm³ and a crystallinity of 12%. The ratio V_2/V_1 was 1.86.

EXAMPLE 37

The procedure of Example 34 was repeated except that the temperature of hot air in the post expansion was 140 °C to obtain a post-expanded foam sheet.

The post-expanded foam sheet had a thickness of 3.01 mm, a density of 0.13 g/cm³ and a crystallinity of 25%. The ratio V_2/V_1 was 2.00.

EXAMPLE 38

The procedure of Example 34 was repeated except that the temperature of hot air in the post expansion was 230 °C to obtain a post-expanded foam sheet.

The post-expanded foam sheet had a thickness of 4.04 mm, a density of 0.097 g/cm³ and a crystallinity of 26%. The ratio V_2/V_1 was 2.68.

EXAMPLE 39

Pre-expansion:

- 5 Pre-expansion was carried out in the same manner as in Example 22 except that the die provided at the extruder head was changed from the circular die to a flat die and a flat plate was used in place of the mandrel. The flat die had a straight line-form extrusion opening having a width of 150 mm and a gap of 0.7 mm. The flat plate was an aluminum plate of 500x500 mm which was cooled with water at 30 °C. The foam sheet was extruded between the aluminum plates, whereby the extruded foam sheet was quenched. In this way, a pre-expanded foam sheet was obtained. The foam sheet had a width of 200 mm, a thickness of 5 mm, a density of 0.52 g/cm³ and a crystallinity of 12%.

Post expansion:

- 15 Post expansion was carried out in the same manner as in Example 29 by bringing the above pre-expanded foam sheet into contact with steam at 100 °C for 7 minutes. There was obtained a post-expanded foam sheet which had a thickness of 12.5 mm and a density of 0.204 g/cm³. The ratio V_2/V_1 was 2.55.

EXAMPLE 40

- 20 Pre-expansion was carried out in the same manner as in Example 39 except that the temperature of the aluminum plates was slightly elevated and the cooling rate of the foam sheet was slightly smaller than that in Example 39 to obtain a pre-expanded foam sheet. The width, thickness and density of the foam sheet were the same as those of the sheet of Example 39. However, the crystallinity was 25%.

25 Post expansion:

Post expansion was carried out in the same manner as in Example 39 to obtain a post-expanded foam sheet which had a thickness of 11.0 mm and a density of 0.232 g/cm³. The ratio V_2/V_1 was 2.24.

COMPARATIVE EXAMPLE 8

- 30 The procedure of Example 22 was repeated except that post expansion was carried out by using hot air at 60 °C in place of warm water at 63 °C and bringing the sheet into contact with hot air for 5 minutes to obtain a post-expanded foam sheet.

The post-expanded foam sheet had a thickness of 1.5 mm and a density of 0.26 g/cm³. The ratio V_2/V_1 was 1.00. Accordingly, the post expansion did substantially not take place.

COMPARATIVE EXAMPLE 9

- 40 The procedure of Example 22 was repeated except that the temperature of water in the post expansion was lowered to 53 °C to obtain a post-expanded foam sheet.

The post-expanded foam sheet had a thickness of 1.5 mm and a density of 0.26 g/cm³. The ratio V_2/V_1 was 1.00 as in Comparative Example 8. Accordingly, the post expansion did substantially not take place.

COMPARATIVE EXAMPLE 10

- 45 The procedure of Example 24 was repeated except that the temperature of steam in the post expansion was lowered to 58 °C to obtain a post-expanded foam sheet.

50 The post-expanded foam sheet had a thickness of 1.5 mm and a density of 0.26 g/cm³. The ratio V_2/V_1 was 1.00. Accordingly, the post expansion did substantially take place.

COMPARATIVE EXAMPLE 11

- 55 Pre-expansion was carried out in the same manner as in Example 40 except that the temperature of the aluminum plates was raised to a temperature higher than that of Example 40 and the cooling rate of the extruded sheet was smaller than that of Example 40 to obtain a pre-expanded foam sheet. The width, thickness and density of the foam sheet were the same as those of the foam sheet of Example 40, but the

crystallinity thereof was 32%.

Post expansion was carried out by bringing the pre-expanded foam sheet into contact with steam at 100 °C for 7 minutes to obtain a post-expanded foam sheet which had a thickness of 5 mm and a density of 0.52 g/cm³. The ratio V_2/V_1 was 1.00. Accordingly, the post expansion did substantially not take place.

EXAMPLE 41

In this Example, the pre-expansion and the post expansion were continuously carried out as shown in Fig. 4. In Fig. 4, an extruder 5 worked in the same manner as in the pre-expansion of Example 22 and continuously delivered a pre-expanded foam sheet. Without winding up the pre-expanded foam sheet, the sheet was successively introduced into a steam tank 6. The temperature of the surface of the sheet was lowered to 30 °C before it was introduced into the steam tank 6. In Fig. 4, a numeral 10 means a winding machine.

The pre-expanded foam sheet was brought into contact with steam at 100 °C in the steam tank 6 for 5 minutes to carry out post expansion. The sheet was then cooled.

The resulting post-expanded foam sheet had a width of 645 mm, a density of 0.07 g/cm³ and a thickness of 5.5 mm and was a low-density fine sheet which was expanded at a high expansion ratio and had fine, uniform cells.

EXAMPLE 42

100 parts of polyethylene terephthalate pellets (trade name: TR8580, manufactured by Teijin Limited) was dried with hot air having a dew point of -20 °C at 160 °C for 5 hours. 0.3 part of pyromellitic dianhydride, 0.1 part of sodium carbonate and 0.6 part of talc as an expansion nucleating agent were uniformly mixed with the pellets in a tumbling mixer. The mixture was fed to the hopper of an extruder (screw diameter: 65 mm, L/D: 35).

Cylinder temperature was 265 to 290 °C, the temperature of the extruder head was 265 °C, die temperature was 265 °C and number of revolutions of screw was 25 rpm. 2.4% by weight of butane as a blowing agent was introduced into the mixture under pressure on the way of the cylinder.

Die used was a circular die having a diameter of 60 mm and a circular die gap of 0.45 mm. A tube was extruded through the port of the die into air and molded into a cylindrical form by means of a cylindrical mandrel while expanding the molten resin and taking off the tube. Part of the resulting cylindrical foam was cut open and the resulting sheet was wound up. In this case, surface temperature was kept at 20 °C while circulating cooling water in the cylindrical mandrel.

The resulting foam sheet had a density (D1) of 0.225 g/cm³, a width of 640 mm and a thickness of 1.6 mm. The sheet had a crystallinity of 9.7% and a glass transition temperature of 75 °C.

A re-heating treatment was carried out by contacting the sheet with heating for 30 seconds by using a hot plate having a surface temperature of 160 °C. There was obtained a post-expanded foam sheet having a density (D2) of 0.133 g/cm³ and a thickness of 2.7 mm. The ratio of D1/D2 by the heat treatment was 1.69.

The crystallinity of the sheet was 24.3%. A sample of 100×100 mm was cut off from the sheet and heated at 200 °C in a constant temperature bath for 30 minutes. The ratio V_a/V_b of the volume (V_a) after heating to the volume (V_b) before heating was 1.02. It was found that the sheet was excellent in heat resistance.

EXAMPLE 43

100 parts of polyethylene terephthalate pellets (trade name: PET10388, manufactured by Eastman Kodak Company) was dried with hot air having a dew point of -20 °C at 160 °C. The dried pellets, 0.25 part of diglycidyl terephthalate (Blemmer® DGT manufactured by Nippon Oil & Fats Co., Ltd.), 0.1 part of sodium montanate and 0.6 part of talc as an expansion nucleating agent were uniformly mixed in a tumbling mixer. The mixture was fed to the hopper of the same extruder as that used in Example 42.

The cylinder temperature was 280 to 290 °C, the temperature of the extruder head was 290 °C, the die temperature was 290 °C and the number of revolutions of screw was 25 rpm. 2.2% by weight of pentane as a blowing agent was pressure-fed to the mixture on the way of the cylinder.

The resulting foam sheet had a density (D1) of 0.242 g/cm³, a width of 640 mm and a thickness of 17 mm. The crystallinity of the sheet was 10.6% and the glass transition temperature thereof was 76 °C.

A re-heating treatment was carried out by contacting the sheet with heating for 30 seconds by using a hot plate having a surface temperature of 160 °C. The resulting sheet had a density (D2) of 0.147 g/cm³ and a thickness of 2.8 mm. The ratio D1/D2 by the heat treatment was 1.65. The crystallinity of the post-

expanded foam sheet was 24.4%. A sample of 100×100 mm was cut off from the sheet and heated at 200 °C in a constant temperature bath for 30 minutes. The ratio V_2/V_1 was 1.02.

EXAMPLE 44

The extruded foam sheet obtained in Example 42 was contacted with heating for 6 seconds by using a hot plate having a surface temperature of 170 °C to obtain a foam sheet having a density (D_2) of 0.106 g/cm³ and a thickness of 3.4 mm. The ratio of D_1/D_2 by the heat treatment was 2.12. The crystallinity of the post-expanded foam sheet was 16.7%.

A sample of 100×100 mm was cut off from the sheet and heated at 200 °C in a constant temperature bath for 30 minutes. The ratio V_a/V_b was 1.06.

EXAMPLE 45

The extruded foam sheet obtained in Example 42 was heated with steam having a vapor pressure of 4 atm for 30 seconds to obtain a foam sheet having a density (D_2) of 0.157 g/cm³ and a thickness of 2.3 mm. The ratio D_1/D_2 by this heating was 1.43. The crystallinity of the post-expanded foam sheet was 24.3%.

A sample of 100×100 mm was cut off from the sheet and heated at 200 °C in a constant temperature bath for 30 minutes. The ratio V_2/V_1 was 0.99.

COMPARATIVE EXAMPLE 12

A sample of 100×100 mm was cut off from the foam sheet which was extruded in Example 42. The crystallinity was 9.7%. The sample was heated at 200 °C in a constant temperature bath for 30 minutes. The ratio V_a/V_b was 1.74. Heat treatment after extrusion was not made. Hence, the sheet was poor in heat resistance and greatly deformed.

COMPARATIVE EXAMPLE 13

The extruded foam sheet obtained in Example 42 was heated with a hot plate having a surface temperature of 140 °C for 10 seconds to obtain a post-expanded foam sheet. The crystallinity was 13.1%. The sheet had a density of 0.114 g/mol and a thickness of 3.15 mm. The ratio D_1/D_2 by this heating was 1.97.

A sample of 100×100 mm was cut off from the sheet and heated at 200 °C in a constant temperature bath for 30 minutes. The ratio V_a/V_b was 1.11.

The results of Examples 42 to 45 and Comparative Examples 12 and 13 are shown in Tables 6 and 7.

Table 6

	Foam Sheet		Post-Expanded Form Sheet		D1/D2
	Density D1 (g/cm ³)	Crystallinity (%)	Density D2 (g/cm ³)	Crystallinity (%)	
Example 42	0.225	9.7	0.133	24.3	1.69
" 43	0.242	10.6	0.147	24.4	1.65
" 44	0.225	9.7	0.106	16.7	2.12
" 45	ditto	ditto	0.157	24.3	1.43
Comp. Ex. 12	ditto	ditto	-	-	-
" 13	ditto	ditto	0.114	13.1	1.97

Table 7

	Foam Sheet (mm)		Post-Expanded Foam Sheet (mm)			V2/V1
	MD	TD	Thickness	MD	TD	Thickness
Example 42	100	100	2.70	99.8	100.4	2.75
" 43	100	100	2.80	99.9	100.3	2.85
" 44	100	100	3.40	99.7	100.2	3.60
" 45	100	100	2.30	99.5	99.5	2.30
Comp. Ex. 12	100	100	1.60	97.0	94.0	3.05
" 13	100	100	3.15	99.4	99.4	3.55

MD: Direction of extrusion of foam sheet

TD: Direction perpendicular to MD

It is clear from Tables 6 and 7 that the volumes of the sheets which were not heat-treated are greatly changed and the sheets are poor in heat resistance. Further, even when the sheets were heat-treated, the sheet having a crystallinity of less than 15% are inferior in heat resistance.

The following Examples 46 to 49 and Comparative Examples 14 to 16 illustrates the extrusion foam sheets of thermoplastic polyester resins and the thermoformability thereof.

EXAMPLES 46 TO 49 AND COMPARATIVE EXAMPLES 14 TO 16

The production unit of extrusion foam sheets, which was used in these examples and comparative examples was a single screw extruder (screw diameter: 65 mm, L/D: 35). The extrusion die was a circular die (bore: 60 mm), and the circular die gap of the extrusion die was changed as shown in Table 9.

The cylindrical mandrel was a water-cooled mandrel (outer diameter: 205 mm, L/D: 1.5).

In the compositions of extrusion foam sheets used in these examples and comparative examples, 100 parts by weight of polyethylene terephthalate (PET) was used as the thermoplastic polyester resin. The resin grade was changed as shown in Table 8. 0.6 part by weight of talc was used as the expansion nucleating agent per 100 parts by weight of PET. Melt property modifiers and metallic compounds used together with the modifiers were changed as shown in Table 8. Liquefied butane was used as the blowing agent in an amount given in Table 8.

Extrusion foam sheets used in Examples 46 to 49 and Comparative Examples 14 to 16 were produced in the following manner.

Polyethylene terephthalate was dried in a dehumidifying drier (160 °C, dew point of -30 °C) for 4 hours. Predetermined amounts of polyethylene terephthalate, modifier, metallic compound and talc were mixed in a tumbling mixer. The mixture was fed to the extruder hopper and melt-mixed. Liquefied butane as the blowing agent was injected into the mixture on the way of the extruder. The mixture was extruded through the circular bore of the circular die into air in the form of a tube. The extrudate was taken while expanding the molten resin, and the foam was cooled by bringing it into contact with the outer surface of the cylindrical mandrel to shape it into a cylinder. Part of the cylindrical foam was cut open and wound up as the foam sheet.

The manufacturing conditions of the extrusion foam sheets used in these examples and comparative examples were as follows.

Temperature of feed zone of extruder: 275 to 285 °C, temperature of compression zone of extruder: 285 to 295 °C, temperature of melting zone of extruder: 265 to 285 °C, temperature of extruder head: 265 to 285 °C, temperature of circular die: 260 to 285 °C, injection pressure of blowing agent: 40 to 140 kg/cm³, and extrusion pressure (head pressure): 50 to 120 kg/cm³. The number of revolutions of screw and take-off speed are shown in Table 9.

The resulting foam sheets were 640 to 643 mm in width. The apparent density, thickness, crystallinity and molecular orientation ratio thereof are shown in Table 10.

The post thermoformer and thermoforming conditions of the extrusion foam sheets which were used for evaluation in these examples and comparative examples, were as follows.

The post thermoformer was a one-shot molding machine for expanded polystyrene, which had a heating zone with infrared radiation and a press part with air cylinder. The molding tool was a plug-assist press tool (bore: 180 mm × 155 mm, depth: 95 mm) for container. Molding conditions were such that 360×360 mm foam sheets were heated at 175 °C in the heating zone for 15 seconds and immediately thereafter, contacted with the thermoformer for 25 seconds to effect the molding.

The resulting molded articles were evaluated by the following criteria.

Appearance

- O: The whole of sheet was uniformly extended, could be molded into the same shape as that of press tool and not broken.
- Δ: Sheet which could be molded into the same shape as that of press tool, but part of surface was broken and cracks were formed.
- X: Sheet which was greatly broken and could not be molded.

Thickness Ratio

The ratio of the thickness of the bottom of the molded article to that of sidewall thereof. The mark "-" shows that the article is greatly broken and measurement cannot be made.

Surface Profile

- O: The surface of the molded article was smooth.
- Δ: The surface was partly uneven.
- X: The surface was considerably uneven.

Overall Evaluation

Evaluation was made as a whole by taking all of the surface profile of the extrusion foam sheet and the appearance and thickness of the post thermoformed article into consideration.

- 5 ⊙: Particularly superior
 ○: Superior
 X: Bad

The results are shown in Table 11.

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Table 8

Polyethylene Terephthalate			Modifier		Metallic Compound		Amount of Blowing Agent (wt%)
Manufac- turer	Grade	Name	Amount (Part by Weight)	Name	Amount (Part by Weight)		
Example 46	Eastman Kodak Company	PET10388	Pyromellitic anhydride	0.3	Sodium carbonate	0.1	1.3
" 47	ditto	ditto	ditto	ditto	ditto	ditto	ditto
" 48	Teijin Limited	TR4550BH	ditto	0.5	ditto	ditto	1.2
" 49	ditto	TR8580	Tetrafunctional epoxy nitride	0.2	Omitted	-	0.7
Comp. Ex. 14	ditto	ditto	Pyromellitic anhydride	0.5	Sodium carbonate	0.1	1.3
" 15	ditto	ditto	ditto	0.3	ditto	ditto	ditto
" 16	ditto	ditto	ditto	ditto	ditto	ditto	ditto

Table 9

		Number of Revolutions of Screw of Extruder (rpm)	Die Temp. (°C)	Circular Die Gap (mm)	Extrusion Rate (kg/Hr)	Take-off Speed (m/min.)	Blow-up Ratio
Example	46	25	265	0.5	23.7	2.16	3.42
"	47	ditto	280	1.0	21.4	2.18	2.63
"	48	ditto	270	0.7	23.7	2.26	3.42
"	49	ditto	265	0.7	21.0	0.72	3.42
Comp. Ex. 14		ditto	280	1.0	21.4	1.45	2.63
"	15	ditto	260	1.0	22.9	1.29	2.63
"	16	ditto	270	0.7	21.0	1.78	3.42

Table 10

	Apparent Density (g/cm ³)	Thickness (mm)	Crystallinity (%)	Molecular Orientation Ratio
5 Example 46	0.19	1.5	10	1.82
" 47	0.18	1.7	11	1.73
" 48	0.16	2.6	18	1.37
" 49	0.63	1.2	7	4.27
10 Comp. Ex. 14	0.19	2.0	11	4.88
" 15	0.23	2.0	10	5.36
" 16	0.18	1.7	22	1.70

Table 11

	Appearance of Molded Article	Thickness Ratio of Molded Article	Surface Profile of Molded Article	Overall Evaluation
20 Example 46	○	1.2	○	⊙
" 47	○	1.3	○	○
" 48	○	1.5	△	○
" 49	○	1.3	○	○
25 Comp. Ex. 14	X	-	○	X
" 15	X	-	△	X
" 16	△	1.5	X	X

Molecular orientation ratio can be adjusted by take-off speed and blow-up ratio, since when the take-off speed of the sheet is increased, the sheet is orientated in the MD direction, while when the blow-up ratio is increased (cooling mandrel diameter is increased), the sheet is orientated in the TD direction. However, when the width and thickness of the sheet and expansion ratio are fixed, molecular orientation ratio cannot be properly adjusted only by the controlling of take-off speed and blow-up ratio. In this case, die temperature is elevated (Example 47, Comparative Example 15).

Molecular orientation ratio can be lowered by reducing the amount of the melt property modifier (Example 47, Comparative Example 14).

Crystallinity can be lowered by lowering the temperature of cooling water for cylindrical mandrel.

Then, a food container of the present invention is illustrated by means of the following examples and comparative examples. Parts given below are by weight unless otherwise stated.

40 EXAMPLE 50

In this Example, the same thermoplastic polyester resin was used for both foam sheet and non-foam sheet.

100 parts of polyethylene terephthalate pellets (trade name: TR8580 manufactured by Teijin Limited) was used as the polyester resin and dried with hot air having a dew point of -20°C at 160°C for 5 hours. 0.3 part of pyromellitic dianhydride, 0.1 part of sodium carbonate and 0.6 part of talc were added thereto. The mixture was uniformly mixed in a tumbling mixer and then fed to an extruder.

The cylinder temperature of the extruder was set to 274 to 287°C and the die temperature thereof was 277°C. About 1.0% by weight of butane as a blowing agent was pressure-fed to the mixture on the way of the cylinder.

A die having a circular gap was provided at the head of the extruder. The polyester resin containing butane was extruded through the circular gap into a cylindrical shape. The extrudate was allowed to proceed on a cylindrical mandrel, while expanding the resin, to obtain a foam sheet. The cylindrical foam sheet was cut open and the resulting flat sheet was wound up into a roll. The resulting foam sheet had a density of 0.262 g/cm³, a thickness of 1.45 mm and a width of 640 mm.

A polyethylene terephthalate resin film (FFL manufactured by Teijin Limited) of 50 μ in thickness was used as the non-foam thermoplastic resin film. This film and the above-described sheet were placed upon each other in layers and put between a pair of rollers to laminate them onto each other. The temperature of

the roller on the side of the foam sheet was room temperature, while the temperature of the roller on the non-foam sheet was set to 135 °C. In this way, there was obtained a laminated sheet in which the non-foam sheet was bonded to only on side of the foam sheet.

A sample having a size of 250×250 mm was cut off from the laminated sheet and preheated by bringing the sample into contact with a hot plate having a surface temperature of 140 °C for 6 seconds. Successively, the preheated sample was put between a male die heated to 180 °C and a female die heated to 180 °C for 6 seconds to thereby mold it into a container and at the same time to accelerate crystallization. Immediately thereafter, the molded article was put between a male die and a female die at room temperature for 6 seconds to cool it, said dies having the same shapes as those of the dies heated to 180 °C. The molding was conducted in such a manner that the non-foam film layer was positioned inside the container. The resulting container had a shape as shown in Fig. 6 and 7.

Fig. 6 shows a side view of the resulting container 7. Fig. 7 shows a plane view of the container 7.

In this molding, the composite sheet increased in expansion ratio and the thickness of the bottom of the container 7 became 3.80 mm.

150 cc of water was put into the container 7 and a lid was put thereon. The container was sealed so that water did not leak therefrom. The container was placed in a 500 W microwave oven and heated for 3 minutes to cause water to boil. Immediately after heating, the container could be taken out from the microwave oven with bare hands. The container did not cause any change by the heating. To make sure, the thickness of the bottom of the container was measured. It was found that the thickness of the bottom was 3.95 mm. The container in the heating within the microwave oven increased in thickness only by 4%. Accordingly, it could be considered that no deformation was substantially caused.

EXAMPLE 51

The foam sheet obtained in Example 50 was used, a polypropylene resin film of 100 μ in thickness was used as the non-foam film and an ethylene-vinyl acetate copolymer resin was used as the adhesive to laminate the films.

One side of the polypropylene resin film was coated with the ethylene-vinyl acetate copolymer resin. The coated side of the film was placed on the polyester resin foam sheet obtained in Example 50. They were passed through a pair of rollers to laminate them. The temperature of the roller on the side of the foam sheet was room temperature, while the temperature of the roller on the side of the non-foam film was 125 °C.

A sample of 250×250 mm was cut off from the laminated sheet obtained above and preheated by bringing the foam sheet side into contact with a hot plate having a surface temperature of 140 °C and simultaneously bringing the non-foam film side into contact with a hot plate having a surface temperature of 100 °C for 6 seconds. Successively, the preheated sheet was put between a male die and a female die for 8 seconds in such a manner that the foam sheet side was contacted with the female die heated to 140 °C and the non-foam film side was contacted with the male die heated to 100 °C, whereby the composite sheet could be molded into a container which was the same as that of Example 50 and at the same time, crystallization was accelerated. Immediately thereafter, the container was put between two dies at room temperature for 6 seconds to cool it, said two dies having the same shapes as those of the dies heated. The molding was conducted so that the non-foam film was positioned inside the container. The foam sheet was swollen by this molding and the thickness of the bottom of the container became 2.94 mm.

In the same way as in Example 50, water was put into the resulting container. The container was heated in the microwave oven. Immediately after heating, the container could be taken out with bare hands. It was found that no deformation was caused after heating. To make sure, the thickness of the bottom of the container was measured. The bottom was 3.05 mm in thickness. An increase in thickness was only 4%. Accordingly, it could be considered that the container could withstand heating by microwave oven.

EXAMPLE 52

The foam sheet obtained in Example 50 was used and a polyethylene terephthalate resin film of 150 μ in thickness was used as the non-foam film. They were laminated onto each other without using any adhesive to obtain a composite sheet. The laminating of the film was carried out by using a pair of rollers in which the temperature of the roller on the side of the foam sheet was room temperature and the temperature of the roller on the side of the non-foam film was 155 °C.

A sample of 250×250 mm was cut off from the laminated sheet. In the same way as in Example 50, a container was prepared from the sample. The thickness of the bottom of the container was swollen to 4.39